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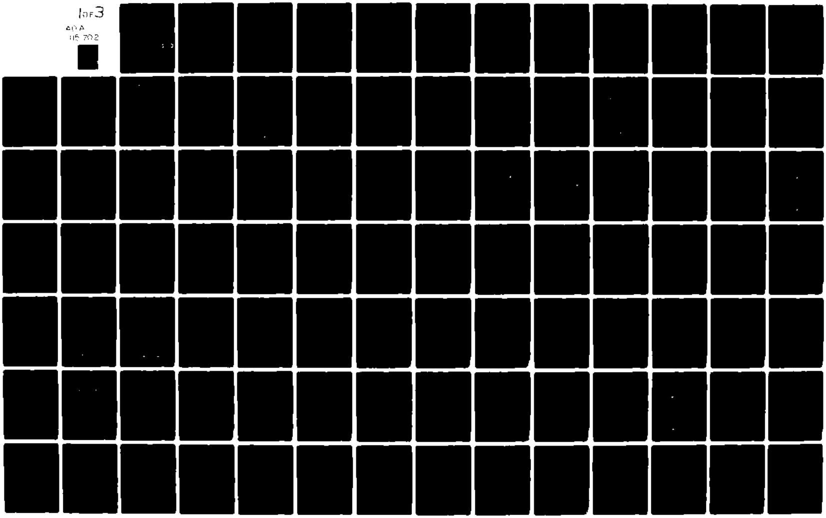

AFIT/GST/OS/82M-1

A WILD WEASEL PENETRATION MODEL

THESIS

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by

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Abstract

Defense suppression of enemy ground forces is basic to successful counterair objectives. The F-4G Wild Weasel (WW) weapon system provides the teeth in getting the defense suppression job done--identifying, locating, and killing enemy ground based threat radars. The objective of this thesis was to develop a methodology that could examine and evaluate the WW defense suppression mission. The problem was developed for a NATO/Warsaw Pact encounter in Central Europe.

A model of the threat environment was built using the SLAM computer simulation language. Threats in the defense sector can be moved as desired. Friendly aircraft can enter the system at a variety of intervals, altitudes, and airspeeds. WWs hunt for threats to attack by searching, identifying, locating, and then launching their weapons at the threat. WW tactics can be changed as the requirements of the mission dictate or at the desire of the WW crew. Self-protection jamming can be selected by either WW or attack aircraft. Enemy threats will fire at an aircraft when the aircraft comes within the threat's range as long as the threat is not engaged with another aircraft. Early warning radars account for threat radar

command and control functions; their control over the associated radars can be changed as desired.

Changing the WW's altitude from 60 meters to 200 meters did not effect friendly attack aircraft survivability. Leading the attack force into the threat area by 30 seconds as opposed to accompanying the attack force did not influence attack force survivability. Further development of the model to include turn-mode capability for the WW weapon and a tactic for pre-emptive weapons launch in anticipation of threat radar radiation is recommended.

A WILD WEASEL PENETRATION MODEL

I. Introduction

Background

The requirement for a weapon system that would deal exclusively with the surface-to-air missile (SAM) threat developed from air battles in the Vietnam War. The North Vietnamese used Soviet SA-2 SAMs in concert with AAA and MIG aircraft to counter a numerically superior air force. To counter these tactics, the USAF developed the F-100/ F-105 Wild Weasel (WW), a weapon system dedicated to the anti-SAM mission.

The current strategy of the Soviet Union and Warsaw Pact countries emphasizes air doctrine through their ground forces to gain superiority on the battlefield (Ref 6:69). Their extensive, sophisticated mobile air defenses, consisting of mixes of guns and missiles, provides overlapping coverage. The net effect is a wide-ranging, protective umbrella for their ground forces.

NATO's task in a confrontation against the Warsaw Pact will be the ultimate test of its airpower capabilities. Counterair operations must gain air superiority over the battlefield if ground forces are to be effective.

USAF Basic Doctrine, AFM 1-1, recognizes this important requirement and now includes defense suppression, along with offensive and defensive counterair operations, as a primary task within the counterair mission (Ref 1:2-16). Defense suppression is a fundamental objective for an effective air-ground force.

The WW weapon system represents a key element in the defense suppression mission. The F-4G aircraft, the current WW used by the USAF, can accomplish defense suppression objectives against threat radar systems by either physically destroying the radars with anti-radiation missiles (ARMs) or bombs, or by causing the radars to cease operation as a precaution against an attack by the WW.

If the F-4G WW is the ideal airpower instrument for suppressing enemy air defenses then the question remains as how best to use this tool to maximum effectiveness. In light of the fact that both the F-4G and its specialized ARM weapons are very limited resources, WW operations must be effective preventing threat radars from attacking friendly aircraft while at the same time surviving attack from these very same radars. The highly fluid arena of the air-ground battle coupled with the expected heavy concentration of enemy radar threats and the diversity of their employment make WW operations a complex and difficult task.

In planning for a defense suppression mission not only must many different factors be considered but also the

underlying relationships between them clearly understood. Aspects such as ARMs employment, force sizing, ingress/egress routing, threat hierarchy, electronic countermeasures, and command and control must be carefully thought out and planned for. In addition, defense suppression operations must be amenable to last-second changes as a result of the evolving air battle.

Needless to say, choosing the best tactic or best set of tactic options for WW operations is not easy. Nonetheless, if counterair operations are to be successful then neutralizing enemy air defenses must be accomplished by WWs using optimum defense suppression tactics.

An analysis for the most advantageous weapons allocation and tactics that explicitly evaluates the WW as a complete system has yet to be accomplished. Although no single weapon system can be expected to successfully counter every aspect of a highly sophisticated threat environment, the F-4G's WW defense suppression effectiveness is a major factor upon which the USAF's counterair mission rests.

Problem Statement

The ability of WWs to perform defense suppression operations in a radar-rich threat environment is basic to successful counterair operations. The objective of this thesis is to develop a methodology, through a simulation

model, for evaluating the WW defense suppression mission. In particular, the methodology should be capable of analyzing force sizing, ARM configurations, and WW tactics. These parameters were selected because they are considered significant areas that impact on the WW mission (Refs 10; 11).

Assumptions and Limitations

Conclusions from this thesis can only be applied within the context of the developed system. Thus, because of the complexity of the WW defense suppression operations, not all components and variables of the system are included. It should be noted that only WW defense suppression operations, and not any other WW mission, are analyzed in this research effort.

The following major assumptions and limitations apply to the system.

1. WWs carry only ARMs. For other types of missions WWs may operate in a mixed-mode configuration (ARMS and hard bombs) or with only hard bombs. For the escort-type scenario in this thesis only ARMs are used.

2. Self-protection jamming is used only by attack aircraft. Jamming pods for WWs are available but are not used.

3. Once a WW begins an attack, the attack is continued until the WW launches an ARM at the threat or the WW is killed.

4. WWs have perfect inter-aircraft radio communications. Although this assumption is open to debate, secure voice radio equipment may insure it.

Results of the thesis are only useful for making relative comparisons between alternatives evaluated. When five out of ten aircraft are predicted to survive for a particular simulation run, given one set of conditions, and only one survives for another set of conditions, the important result is the comparison between the alternatives not the number of surviving aircraft.

Threat Scenario

A WW-threat environment was developed based on confrontation between NATO and Warsaw Pact in Central Europe. The threat consists of a typical Soviet ground army deployed along the forward edge of the battle area (FEBA). A force of WWs are assigned the task of defense suppression in support of a low-level fighter attack force that will penetrate the FEBA and fly through the enemy defenses to strike a target behind enemy lines. For the scenario the WWs can realize their defense suppression objectives by destroying ground-based threat radars or associated early warning (EW) radars.

The air defense elements of a typical Soviet Army, located within an area 50 kilometers wide by 100 kilometers long, consists of approximately 1000 SAMs and AAA units.

Concentrated close to the FEBA will be hundreds of small arms. However, weapons that require optical information to acquire and track targets are marginally effective against high speed, maneuvering aircraft. In addition, Soviet interceptors are hypothesized not to be a factor for the low altitude attack force as their doctrine prescribes operation along the FEBA at or above 10,000 feet, leaving the ground forces responsibility for the air superiority mission up to this altitude (Ref 6:70).

For these reasons the following defense elements were selected as potential threats to the attack force.

1. AAA
2. SAM-A
3. SAM-B
4. SAM-C
5. SAM-D

Command and control of threat radars is represented by EW radars. For this particular threat environment there are eight of these radars positioned in the defense sector.

Structural Model

Figure 1 is the structural model of the air defense developed within the constraints of the scenario. Threats are located in belts that approximate their expected position. Their actual position, however, will depend on battlefield tactics, terrain features, employment

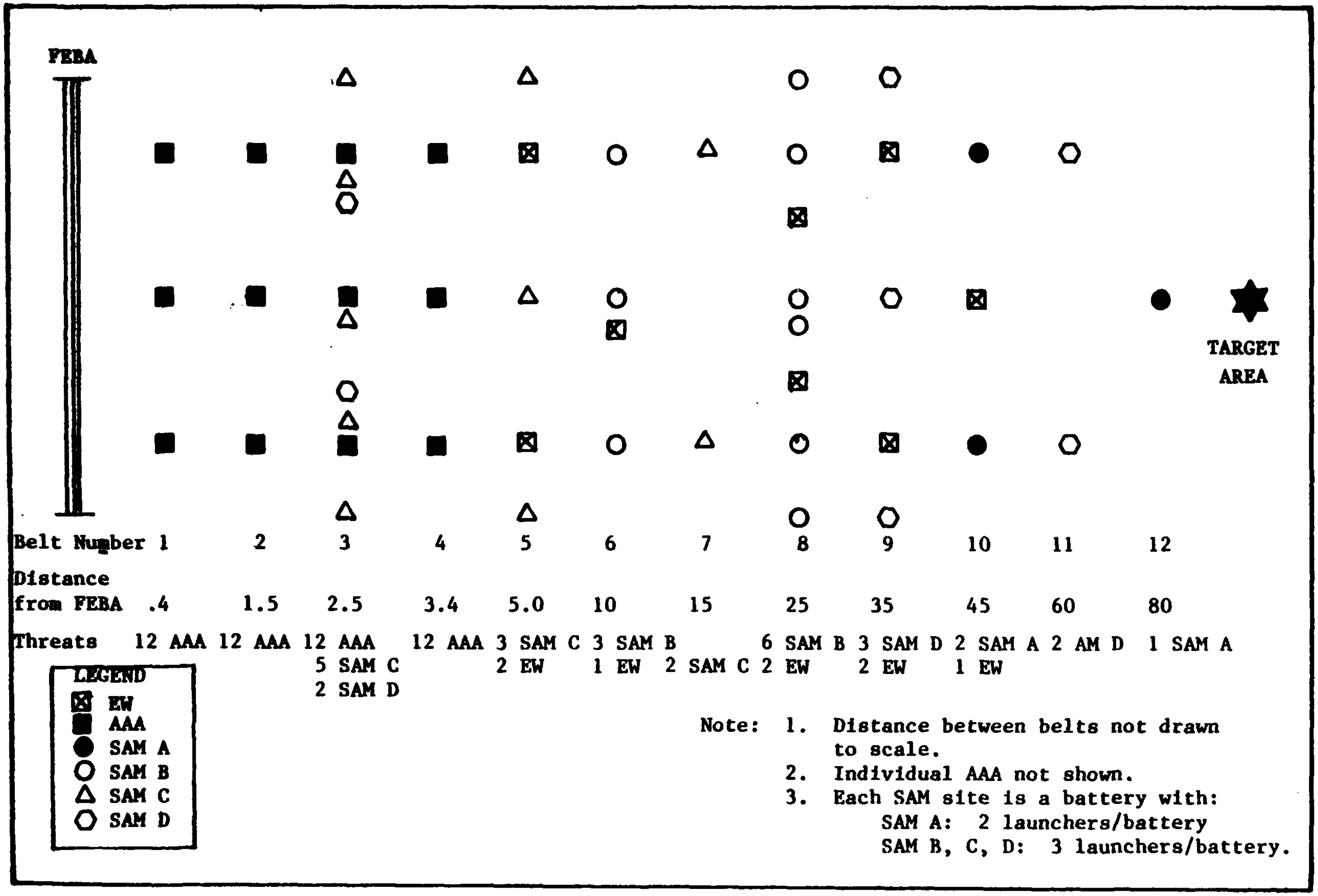

Fig. 1. Structural Model of Defensive Network

doctrine, etc. Note that the number of each threat is specified in Figure 1 but not exact location.

The enemy's area of operation behind the FEBA is modeled by a single line of communication (LOC) road network extending from the target area to the FEBA. The LOC's layout depends on the area's terrain features and the requirements to carry equipment and supplies to the front line. The attack force will avoid any major LOC due to the probable concentration of weapons along it. Accordingly, the LOC for the scenario is hypothesized to lie at the upper portion of the defense area. Figure 2 depicts a typical LOC.

Methodology

WW defense suppression operations are considerably complex involving many dynamic component interactions. Sets of threat radars search for, acquire, track, and attack aircraft that fly through their defense sector. WWs search for, identify, locate, and launch their weapons at threat radars while maneuvering in the battle area. Attack aircraft penetrate then fly through the threat scenario enroute to a target far behind enemy lines.

Because of the complexity of the WW system and the need to study the intricate interplays of the system components, a computer simulation model of the WW defense suppression mission was developed. Simulation was chosen

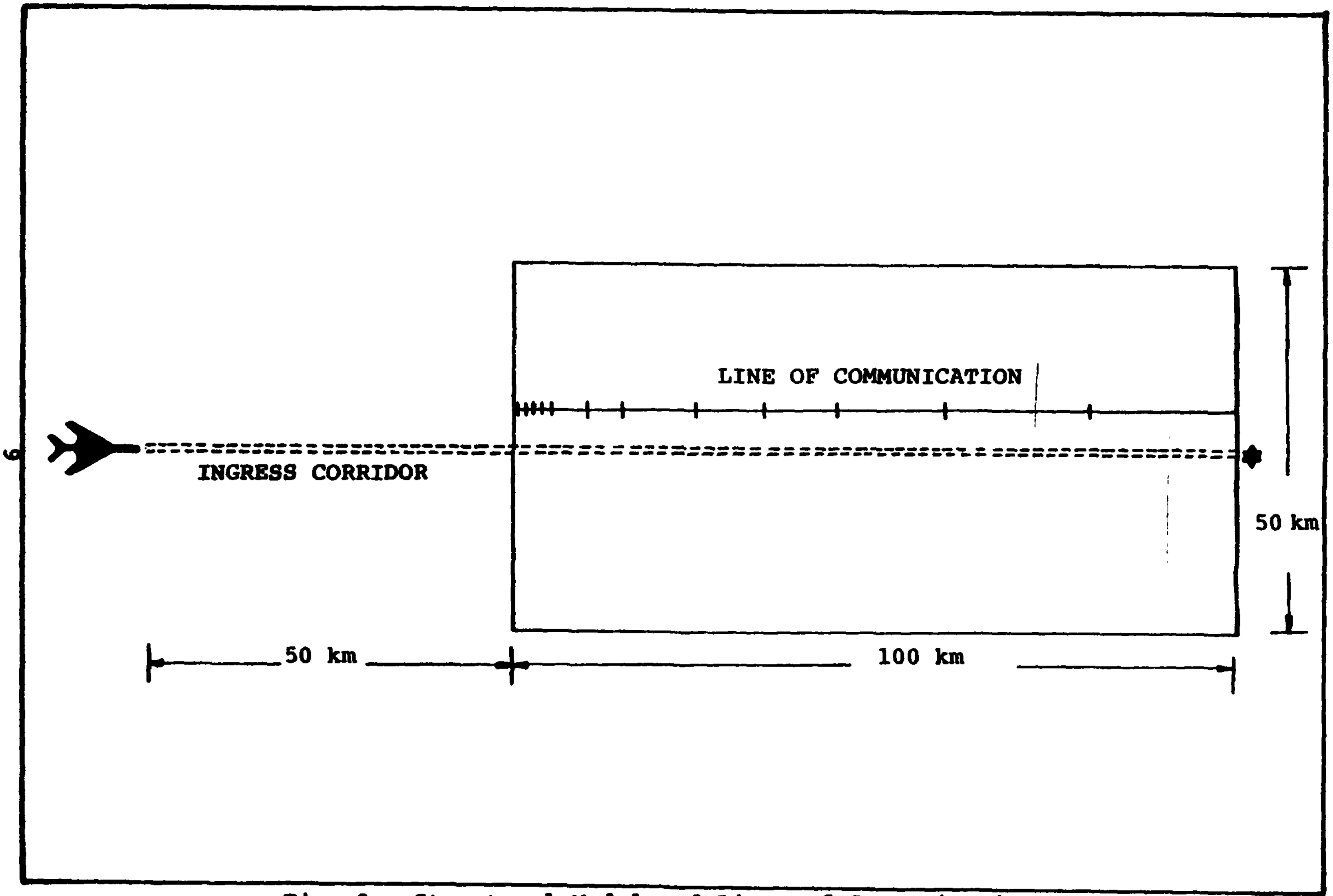

Fig. 2. Structural Model and Lines of Communication

because the problem lends itself to this methodology. Shannon lists several conditions when simulation should be considered for use; two of these cast a strong vote for the defense suppression problem.

1. A complete mathematical formulation of the problem does not exist or analytical methods of solving the mathematical model have not yet been developed.

2. Simulation may be the only possibility because of the difficulty in conducting experiments and observing phenomena in their actual environment (Ref 14:11).

An added and perhaps equally important advantage is that with simulation the complex system under investigation can be expressed in elementary events (Ref 12:3). By formulating the simulation and thus the problem in terms of elementary events complex interactions such as those in the WW defense suppression system can be synthesized.

SLAM was chosen as the simulation language because of the power and flexibility it offered. The dynamic portrayal of the WW attack as well as the threat radar-aircraft interactions were accurately represented through the use of SLAM's language and concept of process orientation. These features will be discussed in detail in Chapter III.

Overview

The thesis is explained in detail in the following chapters. The system structure of the model and the basic components that make up the system are discussed in Chapter II. The simulation model is explained in a logical, sequential manner in Chapter III. In Chapter IV, data collection, experimental design, the results of the experiment, and the validation of the experiment are all discussed. Finally, the results of the thesis are covered in Chapter V and recommendations for follow-on areas are listed in Chapter VI.

II. Systems Structure

Introduction

The purpose of this thesis is to develop a model for investigating the interaction between a friendly aircraft force penetrating the forward edge of the battle area (FEBA) to strike targets in a rear area and the enemy air defense network responsible for preventing this penetration. Two elements comprise the friendly force: a strike force of fighter aircraft and WW aircraft employed in a defense suppression mission. The air defense network is composed of SAM, AAA, and early warning (EW) systems. Possible interaction between the elements include the following:

1. The WW attack and attempt to neutralize any of the air defense systems. Neutralize includes either physically destroying the site or stopping them from radiating.

2. The air defense systems attempt to destroy both strike and WW aircraft penetrating the FEBA.

The model will be used to study specific strike force and WW tactics such as ingress altitude, airspeed, and spacing between aircraft with the ultimate intent of developing procedures designed to increase the overall probability of the strike force successfully penetrating to

the target area. The model must be flexible enough to allow both the size and mix of both friendly and enemy forces to be varied.

Pertinent to the model's development are the major system elements required to describe the system. These elements are the following:

1. The WW aircraft, its associated characteristics and tactics,

2. The strike force, and

3. The enemy defensive network.

This chapter discusses each element separately and in detail. It explains the analytical methodology required by each element to perform its mission.

Wild Weasel Mission Scenario

Today's WW platform is a modified F4-G aircraft containing sensitive radar homing and warning (RHAW) equipment. The WW crew's mission is to search the enemy's area of operation, detect and identify enemy radar signals associated with SAMs, AAA, or EW systems, and force these radars to cease operation by either physically destroying the site with bombs or antiradiation missiles (ARMs) or by causing the sites to stop radiating to preclude being attacked by a WW.

Leek and Schmidt investigated the FEBA penetration and the associated enemy defense network by a flight of

strike aircraft and evaluated the loss rates incurred in the penetration. This thesis extends their analysis by including WW aircraft employed in a defense suppression mission and again evaluates the loss rates of both strike and WW aircraft. In this scenario specific threat locations will not be known before the mission by the WW crews although estimates of the number and type of enemy radars will be provided by intelligence briefings. The WW knows the corridor used by the strike force during ingress to the target. This, along with projected capabilities of the enemy radars, allows the WW to estimate an approximate distance either side of the attack corridor a specific SAM or AAA can be located and constitute a threat to the strike force.

Figure 3 depicts the four phases of a typical WW mission profile: search, detection, ranging, and attack. The figure illustrates the dynamic nature of the scenario. For the mission, the WW aircraft assemble 50 km prior to the FEBA and over friendly airspace. In the search phase the WW proceeds toward the enemy defenses, its RHAW equipment sweeping through radar frequencies attempting to detect and identify enemy radar signals. At detection, the RHAW system alerts the crew to the type of threat, the bearing to the site from the aircraft, and an approximate distance to the threat radar. The WW's onboard processor will refine the site's location to within a few meters during the

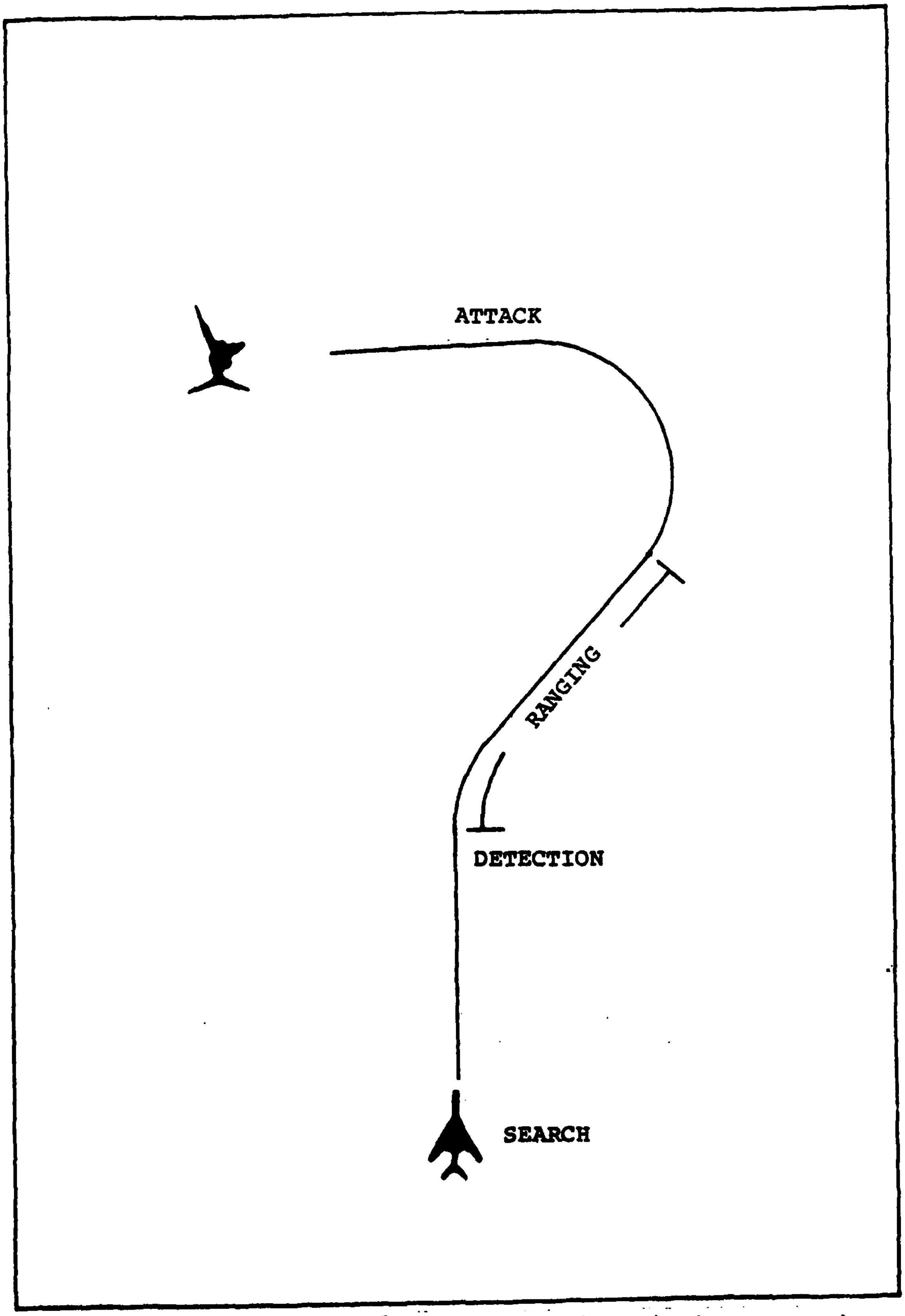

Fig. 3. Wild Weasel Defense Suppression Mission Scenario

ranging phase. Here, the system calculates numerous lines of position (LOP) between the aircraft and the radar site as the aircraft flies through approximately 30 degrees of bearing change. The site's location is estimated to be the intersection of the LOPs. The more LOPs, the more precise the site's location. After completing the ranging routine, the aircraft enters the attack phase by turning toward the site, and for this profile, launching an ARM. After launch the aircraft enters the next search sequence and the process repeats until the WW depletes all its ARMs.

Implicit within the profile description are several areas that must be determined during the mission. Did the search phase start while the threats were beyond the field of view (FOV) of the aircraft or when the sites were inside the FOV? Did the WW maneuver in a direction that allowed it to minimize the amount of time required to complete each profile? What happens if the attack phase occurs inside the minimum launch range of an ARM? These questions and the logic required to evaluate them will be addressed in the following paragraphs.

Threat Detection Criteria

The WW search phase begins well before the FEBA. The minimum distance the WW can detect specific ground-based emitters is limited by either the RHAW receiver's sensitivity or the radar horizon (or FOV) of the aircraft.

Receiver sensitivity indicates the minimum power signal at the aircraft's RHAW receiver that can be processed by the equipment. In certain instances either sensitivity or limited FOV dominates the other in determining the maximum detection range. Which one dominates in the WW case will now be determined.

An aircraft's radar horizon depends on its altitude. The earth's curvature limits the radar horizon of either a transmitter or receiver. (See Figure 4.) The horizon can be approximated by the following equation:

$$R = .868\sqrt{2h} \tag{1}$$

where h = aircraft's altitude, feet; and

R = radar horizon, NM (Ref 5:36).

Converting both R and h to meters, the equation becomes:

$$R = 4117.3\sqrt{h} \tag{2}$$

where h = aircraft's altitude, m; and

R = radar horizon, m.

Thus, an emitter at a height of 60 meters could detect objects out to 32,000 meters (disregarding clutter and terrain blockage). Objects at some height above the earth's surface beyond this 32,000 meter range could extend this detection distance. For example, the same emitter at

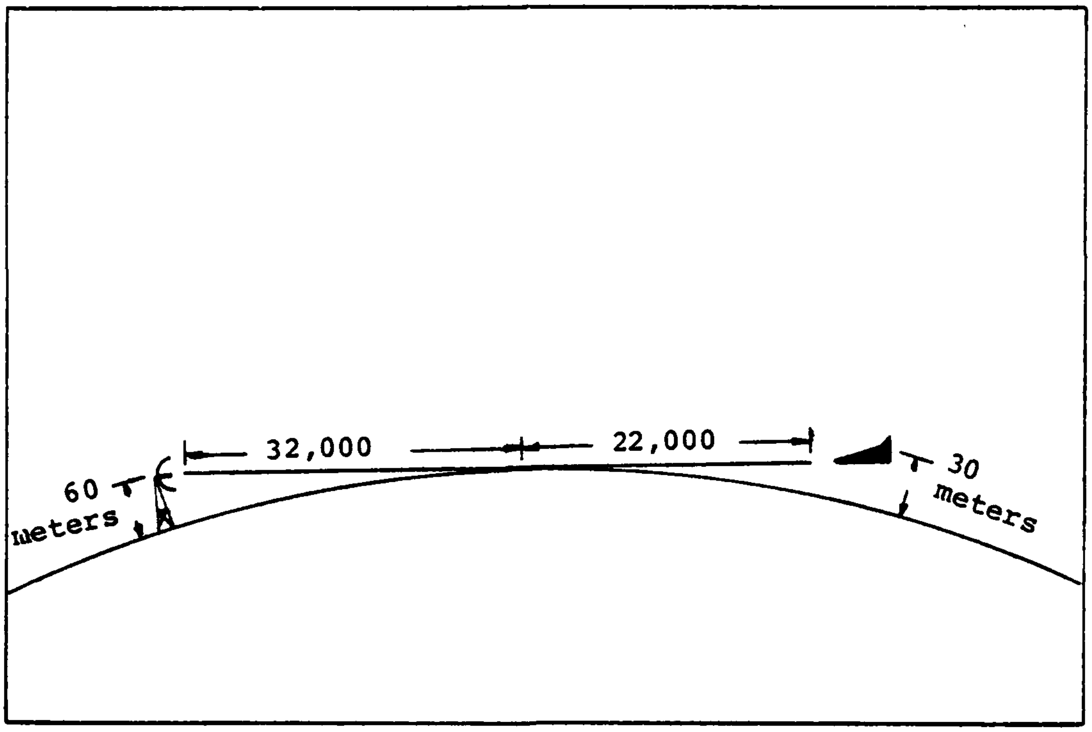

Fig. 4. Radar Horizon

60 meters could detect an object at a height of 30 meters out to 54,000 meters (again disregarding clutter and terrain blockage). For ground based emitters with antenna extending less than 10 meters above the surface, the radar horizon calculations of equation (2) appear sufficient for this model.

Power received at the aircraft, P_r, is proportional to the radar's effective radiated power reaching the WW aircraft (P_tG_t) and the WW effective antenna area, A_e, where P_t is the transmitted power in watts and G_t is the transmitting antenna signal gain in the direction of the WW aircraft. A_e, in square meters, can be approximated as follows:

$$A_e = \left(\frac{c}{f}\right)^2 \frac{G_r}{4\pi} \qquad (3)$$

where c = speed of light, meters per second (mps);

f = radar transmit frequency, in Hertz (Hz); and

G_r = WW receiver antenna gain (Ref 5:18).

For the case of the WW receiver antenna, the gain will be assumed to be one, or the antenna is omnidirectional. Power received at the aircraft is inversely proportional to the receiver's internal losses, L, and the square of the distance between the site and the aircraft, R. Expressed mathematically, P_r becomes:

$$P_r = \left(\frac{P_t G_t}{4\pi R^2}\right) \left(\frac{c}{f}\right)^2 \left(\frac{G_r}{4\pi L}\right) \qquad (4)$$

where all terms are as previously defined (Ref 5:18).

A RHAW receiver is designed to a sensitivity specification determined by the type of signals radiated in the receiver's working environment. Once designed, the minimum sensitivity cannot be changed. If the receiver is too sensitive the processor will be saturated by too many signals; not sensitive enough and many threats will not be detected by the WW until the aircraft is too close to the site. Receiver sensitivity is expressed in decibels (dB) referenced to a specific power level. For this thesis, the reference will be 1 watt and the sensitivity expressed

as dB, watts or dBw. Converting a parameter such as radiated power to dBw is accomplished as follows:

$$P_{t_{dBw}} = 10 \log_{10}(P_{t_{watts}}) \tag{5}$$

Converting all of the terms of the P_r equation yields:

$$P_{r_{dB}} = P_{t_{dB}} + G_{t_{dB}} + 2(c)_{dB} - 2(4\pi)_{dB} - 2(R)_{dB} - L_{dB} - 2(f)_{dB} \tag{6}$$

For a given aircraft/radar encounter all terms in the P_r calculations can be assumed to be constant except P_r, R, and G_t. Table I depicts typical values for P_r, f, and L in the FEBA. Rearranging equation (6) and solving for G_t in terms of P_t and R yields:

$$G_{t_{dB}} = 2(R)_{dB} - P_{t_{dB}} + 2(4\pi)_{dB} + P_{r_{dB}} + L_{dB} + 2(f)_{dB} - 2(c)_{dB} \tag{7}$$

where all terms are as previously defined.

TABLE I

AVERAGE SYSTEM PARAMETERS

Parameter	Normal Units	Decibels (dBw)
Transmit Power, P_r	50-100 kw	47-50
Radar Frequency, f	10-15 GHz	100-102
System Losses, L	-	10

Setting P_r to the receiver sensitivity, S, at the aircraft, equation (7) becomes an equation for G_t in terms of R alone. A receiver sensitivity of -100 dBw is both technologically feasible and operationally effective. Setting P_r to -100 dBw equation (7) becomes:

$$G_{t_{dB}} = 2(R)_{dB} - 80.6 \text{ dB} \quad (8)$$

As a limit of the G_t required to process a signal assume R is the radar horizon of an aircraft flying at an altitude of 100 m (R = 41,173 m or 46.15 dB). Solving equation (8) for G_t yields:

$$G_{t_{dB}} = 92.3 - 80.6 = 11.7 \text{ dB} \quad (9)$$

Typical values for the main beam G_t near the FEBA are 40 dB with an average sidelobe gain 20 dB down from this maximum, or the average sidelobe G_t of 20 dB. Since the receiver requires only 11.7 dB (or 28.3 dB below maximum) at the radar horizon, the system could identify radars when receiving sidelobe level energy signals or, stated another way, the receiver could process radar signals from an emitter where the antenna main beam is randomly oriented with respect to the WW. For this reason, the aircraft's FOV and not the receiver sensitivity limits the WW in detecting threat radars in this model.

Wild Weasel Heading System

The continuous time model allows the WW aircraft to maneuver in response to a threat. A heading reference system (HRS) similar to an aircraft's horizontal situation indicator or compass was developed to follow an aircraft throughout its mission. By using this HRS the key elements of the WW's low altitude mission could be determined. Four quantities defined by the HRS are listed below and described in the following paragraphs:

1. The WW's heading, H;

2. The magnetic bearing from the aircraft to the site, B;

3. The absolute bearing, AB; and

4. The relative bearing.

The WW's heading, H, is the direction of the aircraft's flight vector referenced to North or 000 degrees and is calculated as follows. (Note: the model assumes a no-wind condition, thus the aircraft's flight vector, velocity vector, and heading are aligned.) An initial heading, H_i, and a rate of heading change with time, ΔH, are initially specified. A left hand turn results in negative ΔH and a right hand turn, a positive ΔH. The new heading, H_n, Δt time units later is determined as follows:

$$H_n = H_i + (\Delta H)(\Delta t) \tag{10}$$

A 360 degree correction factor limits the value of H to 0-360 degrees. For example, if the WW's heading, H_i, was 010 degrees and a left hand turn of four degrees per second for five seconds is required, equation (10) calculates a new heading, H_n, of -10 degrees. The correction factor of + 360 degrees is applied to negative headings, and H equals 350 degrees.

The magnetic bearing, B, locates the threat radar site with respect to the aircraft and as was true with H, is referenced to North or 000 degrees. B depends on the relative position of the aircraft with respect to the radar. Figure 5 depicts the airspace around an emitter, S, divided into four quadrants. For each quadrant the angle θ is calculated as follows:

$$\theta = \tan^{-1}\left(\frac{Y_S - y_A}{X_S - x_A}\right) \tag{11}$$

where Y_S = y coordinate of the threat radar,

X_S = x coordinate of the threat radar,

y_A = y coordinate of the aircraft, and

x_A = x coordinate of the aircraft.

Knowing the magnitude of the Tan θ and the magnitude of the quantity (Y_S - y_A) the aircaft, A, is located in a specific quadrant around the threat radar. For example, consider an aircraft located in quadrant II. The quantity (Y_S - Y_A) is positive, and the quantity

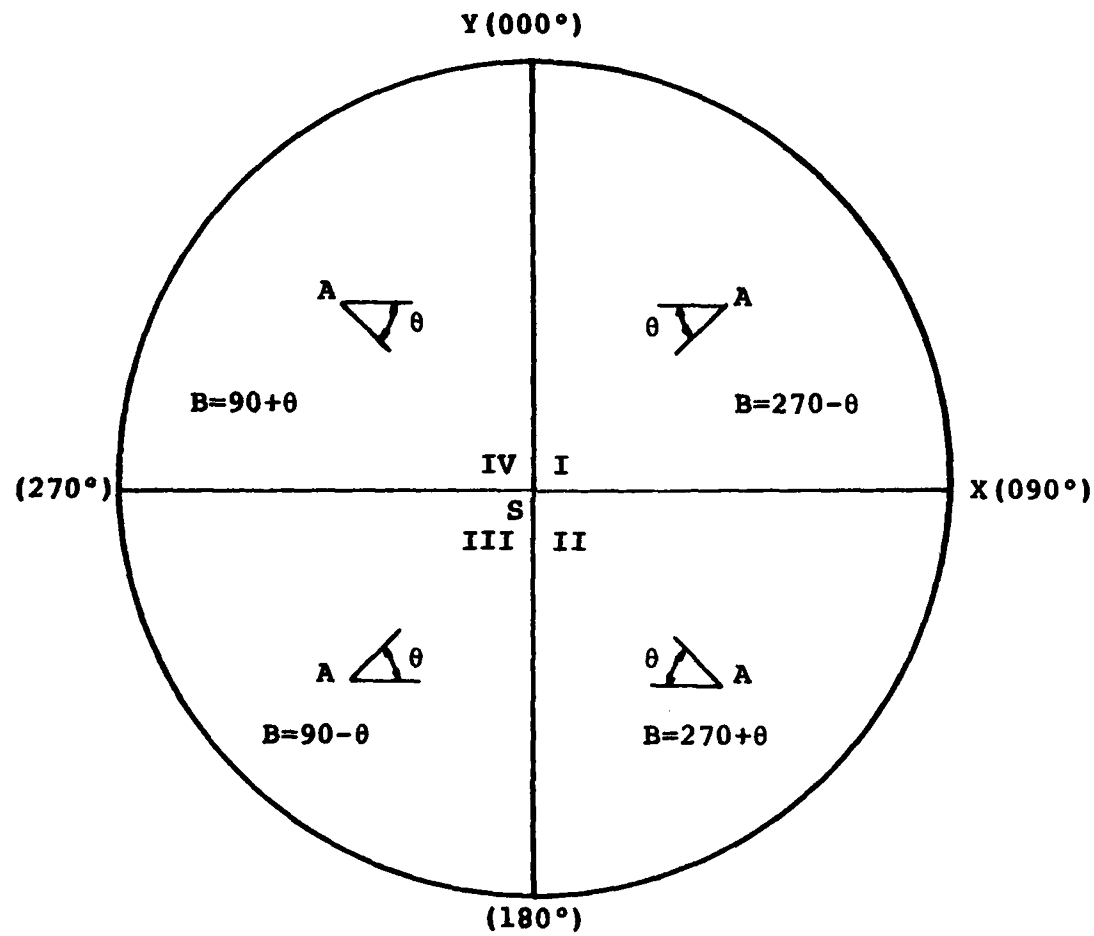

Fig. 5. Magnetic Bearing Determination

$(X_S - x_A)$ is negative. Tan θ will be negative. A negative tan θ and a positive $(Y_S - y_A)$ occurs only in quadrant II. B is then referenced to 000 degrees by either adding θ to or subtracting θ from one of two cardinal headings--090 or 270 degrees. The B calculation for each quadrant around site S is also depicted in Figure 5.

The absolute bearing, AB, is the abaolute value of the difference between the heading, H, and the magnetic bearing, B, or:

$$AB = \text{Absolute value } (H-B) \tag{12}$$

All of the WW's low altitude ranging routines are simulated by calculating the value of AB. For instance, after detecting a threat radar and with both H and B known, the WW will start turning until AB reaches 75 degrees, the hypothesized value of AB required to start the WW's LOP calculations. The WW will stop the turn and allow AB to increase to 105 degrees to simulate the entire ranging routine.

As will be shown, AB is used in the relative bearing calculations and is limited to a maximum of 180 degrees. For computed values greater than 180 degrees, a new value is calculated as follows:

$$AB = 360 - AB \tag{13}$$

Knowing H, B, and hence, AB, the WW can accomplish its low altitude attack profile in both a minimum time and airspace. Also, by knowing these terms, a fourth quantity of the HRS is specified--the relative bearing, RB. RB is the bearing of the site from the aircraft referenced to the aircraft's current heading. If $(H > B)$, the site is located AB degrees to the left of the aircraft. If $(B > H)$, the site is located AB degrees to the right of the aircraft. Subsequent turns away from and toward the site will be made in reference to the current RB. Figure 6 depicts an aircraft heading 090 degrees with a RB of 045 degrees to the site, S. Since $(H > B)$, the site is located $(90 - 45)$ or 45 degrees to the left of the aircraft.

Slant Range to Site Calculations

After developing a HRS, the analytical model continued by calculating the slant range, SR, between the radar site and the WW aircraft for each time increment during the simulation run. Solving for SR by triangulation:

$$SR = \sqrt{(Y_S - y_A)^2 + (X_S - x_A)^2 + ALT^2} \qquad (14)$$

where ALT = the aircraft's altitude, meters (m), and other terms as previously defined.

As the aircraft proceeds toward the FEBA, its x and y position change continuously, and the SR to a specific

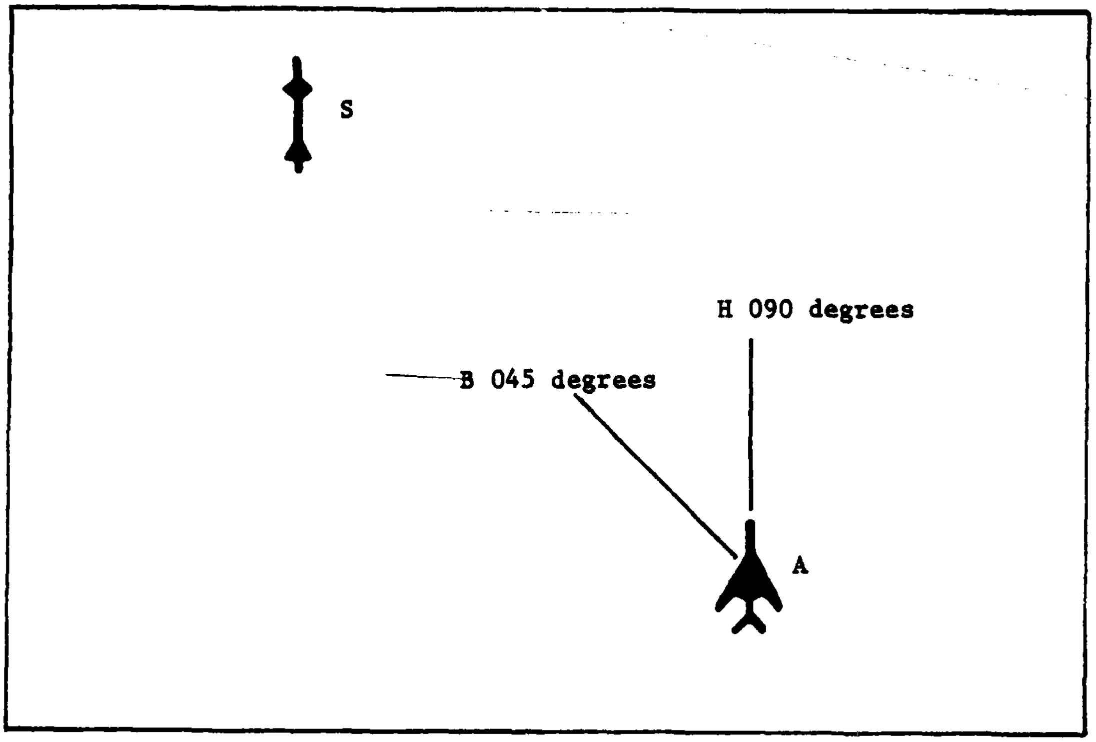

Fig. 6. Aircraft/Site Relationship

site also changes. When the SR to a site decreases to less than the WW's FOV the model assumes the site has been detected. In the model detection includes both determining the type of radar and its RB from the aircraft's current position. After detecting the threat, the WW maneuvers to a position from which the ranging phase of the profile can be accomplished. For this thesis, the aircraft will turn in the shortest direction to achieve a 75 degree AB. For an operational WW system the entire ranging routine requires continuous LOP calculations for a 30 degree change in AB. Thus, the ranging requires AB to increase from 75 to 105 degrees. Figure 7 depicts the reason 75

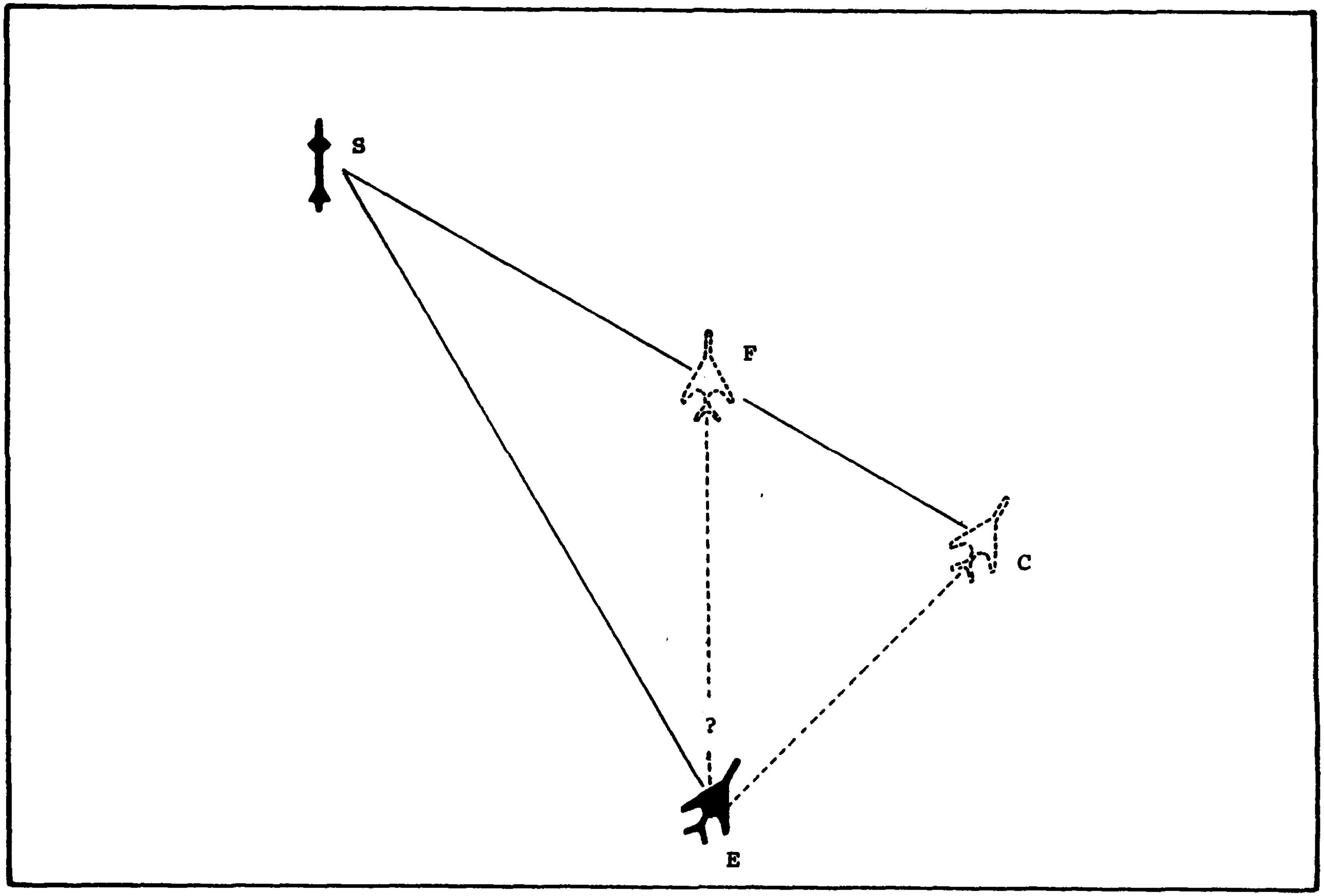

Fig. 7. Wild Weasel Ranging Problem

degrees AB was chosen as the initial rollout bearing. An aircraft would need to fly the distance EF to achieve a 30 degree AB change if the initial AB was 30 degrees, but a shorter length leg (EC) for an initial AB of 90 degrees. By making the required AB change symmetrical about the 90 degree AB, a minimum ranging time duration can be achieved. This technique is similar to an aircraft flying an arc about a TACAN station. Thus, the initial and final AB were chosen to be 75 and 105 degrees (90 ± 15).

Wild Weasel Turn Direction Algorithm

The first pilot input to the WW flight scenario is to determine the initial turn direction required to achieve the desired AB of 75 degrees. As was mentioned earlier, time is critical during the ranging routine. The WW's self-protection and evasive tactics are limited during this time period, so, the turn to 75 degrees should be in the direction which takes the shortest time. In the aircraft, the decision is simple. The pilot looks at his RHAW display and determines the RB to the site. He turns either left or right depending on the value of RB. If the site is at the pilot's 10 O'clock position (as in Figure 6), the turn will be to the right.

Converting from the pilot "seeing" the RB to the model computing the direction can be accomplished once the B and AB have been calculated. The initial decision is to

compare the site's x coordinate, X_S, with the aircraft's x coordinate, x_A. If $(X_S > x_A)$ the bearing to the site (in degrees) will fall in the range $(000 < B < 180)$. Next, the model analyzes which side of the site the aircraft will pass or has passed, if the aircraft maintains a constant H. From Figure 6, the aircraft will pass to the right of the site if it continues on its present heading. Converting to the model's logic, if $[B < H < (B + 180)]$, the aircraft will pass to the right of the site. Again, from Figure 6, the aircraft's H is 090 degrees, the B to the site is 45 degrees. The heading falls in the range of $(45 < 90 < 225)$ and satisfies the requirement for passing to the right of the site.

After determining the site's position in relation to the aircraft and whether the aircraft will pass or has passed to either the right or left of the site, the final comparison checks the magnitude of AB. If $(AB < 75)$ degrees the turn will be made to increase AB to 75 degrees. If $(AB > 75$ degrees) the turn will be in a direction to decrease AB to 75 degrees. This completes the logic required to turn the aircraft in the shortest direction to initiate the ranging phase.

At the completion of ranging, the aircraft turns again, this time toward the site and prepares for the attack phase. This second turn direction is dependent only on the site's position in relation to the aircraft

prior to the initial ranging turn. Table II summarizes all positions and relative bearing combinations prior to the initial turn with the decision blocks indicating the direction of the initial turn to start the ranging phase and the second turn to initiate the attack phase. For example, for the aircraft in Figure 6, it is to the right of the site and AB $<$ 75 degrees. To start the ranging, the aircraft would turn right and to start the attack phase the second turn would be to the left.

TABLE II

WILD WEASEL TURN LOGIC

Side of Closest Approach to Site	$\leq$ 75		> 75	
	Ranging Turn	Attack Turn	Ranging Turn	Attack Turn
Left	Left	Right	Right	Right
Right	Right	Left	Left	Left

Addressing the requirement for turning in the shortest direction, a question arises as to how much time is saved in a WW mission scenario by turning in the shortest direction. Figure 8 depicts to scale the situation where a WW detects a threat at a point, turns in the shortest direction to initiate ranging, then turns in the shortest direction to attack the site. Figure 9 shows the aircraft under the same initial AB and H conditions,

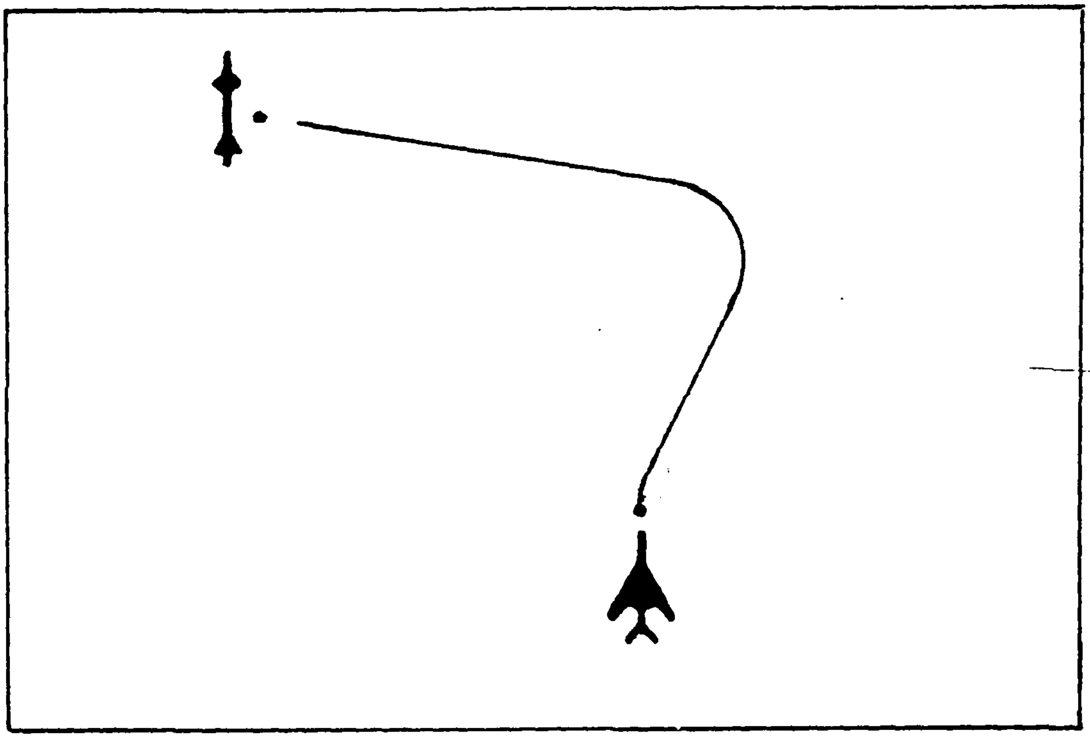

Fig. 8. Correct Turn Maneuvering

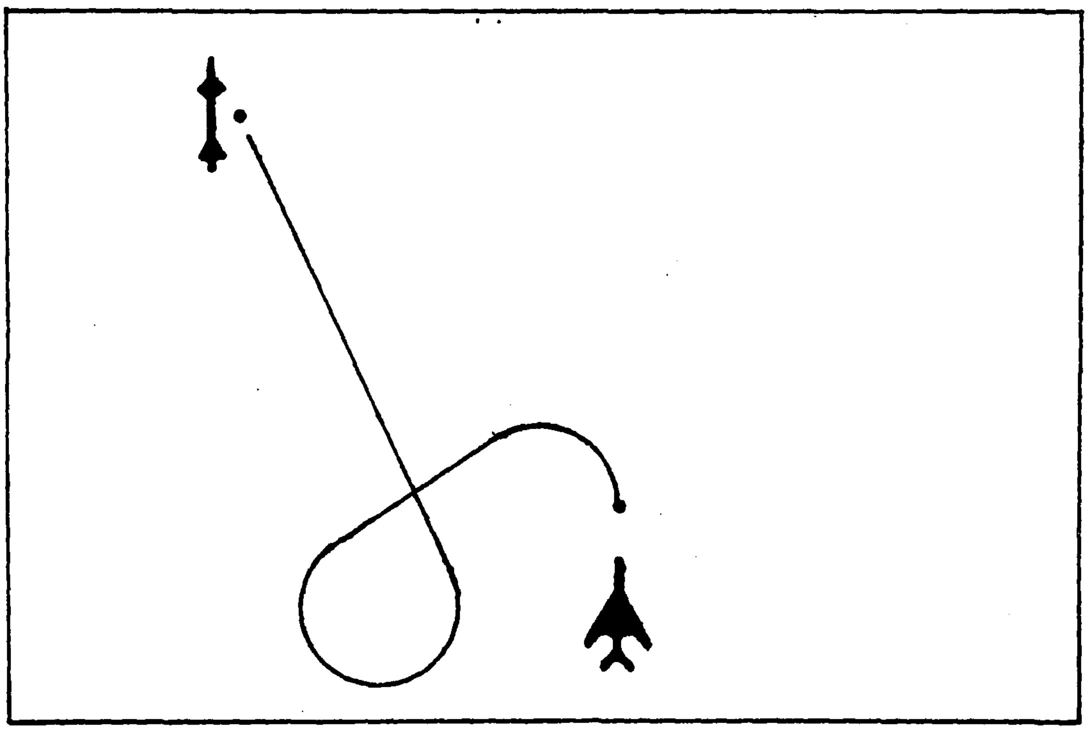

Fig. 9. Incorrect Turn Maneuvering

but which maneuvers in the incorrect direction for both turns. The increased time required by the "wrong turn" aircraft in completing the profile can be translated into fewer sites attacked during a mission or increased exposure to the enemy threats. This increased exposure translates into an increased probability of either being detected by the enemy sites or by being destroyed after being detected. Thus maneuvering in the shortest direction to achieve the required AB increases the number of sites attacked per mission and may decrease and probability of the WW being destroyed.

Attack Phase of WW Profile

The final and most important phase of the WW's mission profile is the actual attack of the site. After completing the ranging phase and with an accurate estimate of the site's location the WW turns back toward the threat. In this thesis the aircraft stops turning when its flight vector aligns with the site's location and the WW is boresighted on the threat (AB = 0 degrees). Although not required by all types of ARMs, boresighting on the threat increases the ARM's delivery accuracy. Any launch azimuth off of boresight results in a decreased delivery accuracy.

The WW carries two types of ARMs: a type B designated for a long range launch and an older, shorter range missile designated type A. For a given launch speed and

altitude each ARM has an associated envelope that denotes the minimum and maximum firing distances, representative flyout velocities, and an associated P_k. For the WW altitude used in this model, these hypothesized parameters are shown in Table III. Given the increased P_k for ARM type B, the decision logic for selecting a weapon will be as follows. If any type Bs are left, the WW crew selects a type B weapon.

TABLE III

ANTI-RADIATION MISSILE (ARM) CHARACTERISTICS

	Type	
	A	B
Average Velocity (m/sec)	350	450
Probability of Kill (P_k)	.8	.85
Range (m) (Min/Max)	8000/15,000	8000/25,000

This thesis assumes weapons delivery accuracy is independent of launch range when launch occurs in the launch window. After boresighting on the threat the WW's next action depends on the slant range to the site. Three possible conditions exist:

1. The SR falls in the launch envelope,

2. The SR is greater than the maximum launch range (R_{max}), or

3. The SR is less than the minimum launch range (R_{min}).

If the SR satisfies the first case, the launch point will occur somewhere between the current SR and the R_{min}. The model assumes that any point between SR and R_{min} is equally likely and determines a launch range, R_{lau}, based on a uniform probability distribution between SR and R_{min}.

For case 2, the aircraft must delay launch until it enters the launch envelope. Here, the launch point is assumed to be uniform between R_{max} and R_{min}. For both cases 1 and 2 the WW proceeds toward the site until its SR reaches R_{lau}, launches the ARM, allows the weapon to clear the aircraft (assumed to be launch time plus five seconds), and begins searching for the next threat.

Case 3 requires the WW to maneuver away from the site. Using the turn algorithm, the WW aircraft turns away from the site until AB = 180 degrees, rolls out of the turn, and proceeds outbound until the SR to the site increases to 18,000 meters, reverses its turn and bore-sights on the site. This insures the second attack will fall in case 2 and a launch will culminate the attack. The case 3 profile typifies action required by the WW in a threat-rich environment given the launch envelope of the ARMs.

WW Defense Suppression Mission Summary

In summary, three key elements comprise the WW's defense suppression system structure:

1. The heading reference system (HRS) and its associated logic,
2. The aircraft maneuvering logic, and
3. The Defense Suppression Mission Phases.

The HRS can be compared to an aircraft's horizontal situation indicator. It allows the model to describe a threat radar's position in relation to an aircraft's current position and heading. The first two outputs calculated by the HRS are the aircraft's heading and the magnetic bearing to a threat radar site. These two elements, in turn, define a third quantity, the relative bearing of the threat radar to the aircraft's current heading. Knowing these three elements allows the model to solve the maneuvering logic to accomplish the mission scenario.

Four key phases of the defense suppression mission scenario are the following:

1. Search,
2. Detection,
3. Ranging, and
4. Attack.

The search phase occurs when the WW has weapons remaining and is attempting to locate a target to destroy. At detection, the aircraft's RHAW system alerts the crew to a potential target. During ranging, the WW's onboard processor refines the site's location estimate to within a tolerance required by the aircraft's weapons. The attack phase culminates the mission scenario. The aircraft selects an ARM and launches it against the site. The mission scenario continues until the WW exhausts its ARMs.

Although important to the overall success of the mission, the WW egress from the target area was not addressed in this chapter. The model will handle egress by assigning the x and y coordinates of (0, 25000 m) as the site coordinates of the next target when all ARMs are depleted. The WW turns toward this point, boresights on it and departs the enemy portion of the FEBA.

Strike Aircraft System Structure

The strike aircraft flight forms with the WW over friendly territory well before the FEBA. The planned ingress corridor keeps the strike force as far away as possible from the enemy's main lines of communication (LOC) (Ref 9:83). The enemy uses these LOCs to transfer troops and equipment forward to and away from the FEBA, and thus, concentrates his defenses near them. The mission's target is located in an area 95 km behind the FEBA. The aircraft

penetrate the FEBA near the target's latitude at an altitude of 200 m. The speed to the target is a constant 480 kts (247 m/sec). No aircraft turning in response to threats is modeled and the ingress heading is kept constant at 090 degrees.

Defensive System Structure

The final system element is the defensive array the WW and strike aircraft will attempt to penetrate. The major areas addressed in this section are the following:

1. Radar system characteristics and limitations,
2. SAM probability of kill calculations,
3. Intercept geometry calculations,
4. Specific differences with previous modeling efforts,
5. AAA probability of kill calculations, and
6. Command and control.

Radar System Characteristics and Limitations

The radar systems composing the defensive network can be characterized by certain system parameters listed in Table IV (Ref 9:18). The P_t, G_t, and RF are the same parameters defined in the receiver sensitivity section of this thesis. The maximum range and minimum altitude represent restrictions on either the radar itself or the missile associated with the radar. The acquisition and

TABLE IV

DEFENSIVE SYSTEM PARAMETERS

System	Transmit Power, P_r (kw)	Antenna Gain, G_t	Maximum Detection Range (m)	Minimum Engagement Altitude (m)	Lethal Radius (m)	Acquisition Tracking Time (sec) Minimum	Acquisition Tracking Time (sec) Maximum	Average Missile Velocity (mps)	Confounding Delay (sec)
AAA	123	40	2,990	0	-	6	25	-	30
SAMA	600	31.7	50,050	91.0	56.4	18	51	592	13
SAMB	100	42	74,150	305.0	43.6	12	26	759	15
SAMC	200	41	22,250	15.0	26.2	17	38	599	30
SAMD	100	43	10,200	45.0	22.0	10	23	525	30

tracking time is the time required by the system operators after detecting an aircraft to evaluate the flight path and to determine if the probability of destroying the target warrants further tracking by the site. At its minimum limit, it represents the minimum time after detecting a threat for a site to schedule a missile launch. The missile velocity is the average velocity of the missile from launch to detonation. In this thesis missile acceleration will not be modeled. The confounding delay is the minimum time required by the site to prepare the system for the next engagement. Typical examples of confounding delays could be the time after missile detonation required by the site before searching for a new target or the time for a site to access a target disappearing from its radar scope (an aircraft going out of range or being destroyed by another site).

For this thesis' model, the defensive radar site must be capable of analyzing aircraft engagements from any attack azimuth and heading. Additionally, the aircraft can employ either jamming (wet) or nonjamming (dry) tactics (WW aircraft do not operate ECM equipment during a defense suppression mission profile).

The methodology required for determining the probability of destroying the attacking aircraft will be developed in the following paragraphs.

Radar system parameters such as the pulse repetition interval (PRI) determine the maximum range most radars can detect and track a target. The accuracy achieved by these radars and their associated missiles has led the attacking aircraft force to employ low altitude penetration as one means of increasing its probability of reaching the target area. The low altitude penetration complicates the radar tracking problem because it introduces the multipath signal problem. Below a certain altitude, the reflected radar return from a target interacts with a mirror image signal reflected off the earth's surface at the radar processor (Ref 15:172). Because the target return interferes with and cannot be distinguished from the mirror image, accurate tracking cannot be accomplished. The signal can induce wild fluctuations in the radar's range gate and causes the return to "break lock." At some elevation angle, referred to as the multipath angle, the difference in the arrival time between the signal and its mirror image is great enough that the two signals can be distinguished and accurate tracking of the actual return becomes possible. For the radars in this thesis, an average multipath angle of .25 degrees will be used. This represents an average of the values used by Leek and Schmidt (Ref 9:15). Thus, in addition to being inside the maximum detection range of a radar, the aircraft

must be at an elevation angle, α, above the horizon such that $\alpha > .25$ degrees, where α is defined as follows:

$$\alpha = \sin^{-1}\left(\frac{ALT}{SR}\right) \qquad (15)$$

where ALT = altitude of the aircraft, and

SR = slant range from the radar to the aircraft.

After detecting the aircraft, the radar site attempts to track the target and launch its missile in such a manner as to achieve the highest probability of kill (P_k). In a similar manner to Leek and Schmidt, this thesis evaluates the P_k in terms of the missile's lethal radius (LR) and the circular error probable (CEP) (Ref 9:19-22). LR is the distance from the SAM's detonation point where as many aircraft survive as are killed by the detonation beyond it. CEP is the error associated with the distance measured between the desired and actual point of impact (Ref 2:44). More precisely, CEP or spherical error probable, is a sphere around the target aircraft within which 50 percent of the missiles fired under a given set of conditions will detonate (Ref 9:19). Thus, P_k, evaluated in terms of CEP and LR reduces to the following equation:

$$P_k = 1-(.5)^{(LR/CEP)^2} \qquad \text{(Ref 9:22)} \qquad (16)$$

For a specific SAM system, LR is a constant. By decreasing CEP, the missile's P_k increases; for the highest P_k, the missile must deliver its missiles with the smallest CEP.

CEP calculations depend on whether the target aircraft is either wet or dry--either jamming or not jamming. Leek and Schmidt evaluated the wet case where CEP is determined as follows:

$$CEP = \sqrt{A(J/S)R_i^2+B(J/S)+C} \qquad (17)$$

where A, B, and C = constants dependent on the type of SAM,

R_i = range from the launch point to the target, and

J/S = the jamming to signal ratio.

The range to intercept, R_i, will be evaluated later in this section for all intercept cases. (J/S) is dependent on the range from the radar to the target aircraft, the effective radiated power (ERP) of the aircraft's jammer, the technical parameters of the radar, and σ_{RCS}, the radar cross-section (RCS) of the target aircraft. RCS is dependent on the intercept geometry between the aircraft and radar and represents the amount of reflected signal energy reradiated back toward the radar. It is usually expressed in decibels referenced to square meters of reflected signal strength. Table V lists the RCS in

TABLE V

RADAR CROSS-SECTION OF FIGHTER
AGAINST DEFENSIVE SYSTEMS

	Radar Cross-Section (in dBm^2)		
Aspect (Degrees)	SAM-A	SAM-B, SAM-C	SAM-D, AAA
0.	10.75	3.60	8.20
5.	4.75	.40	6.70
10.	4.65	2.55	1.90
15.	-2.33	3.03	3.48
20.	4.80	1.70	.85
25.	2.75	2.50	3.95
30.	1.20	10.65	5.20
35.	-1.65	7.95	-1.20
40.	2.15	3.45	1.70
45.	4.70	3.70	6.35
50.	1.75	-.95	3.10
55.	1.10	-.65	1.00
60.	-4.00	-.95	1.90
65.	.43	.05	.25
70.	9.23	8.45	8.19
75.	13.73	14.55	13.43
80.	13.98	16.35	16.70
85.	16.38	16.00	16.08
90.	25.85	24.98	24.38
95.	20.88	19.95	19.23
100.	17.00	15.75	16.58
105.	7.03	9.20	5.83
110.	9.80	8.73	9.50
115.	1.75	3.65	6.20
120.	-.75	2.33	7.85
125.	-.23	3.13	4.28
130.	-2.33	3.03	3.48
135.	.08	-1.08	4.35
140.	-1.28	-2.60	3.90
145.	-1.90	.50	6.00
150.	2.78	.55	5.23
155.	6.55	.43	6.93
160.	.50	.58	2.95
165.	.55	6.38	4.73
170.	4.15	6.53	9.93
175.	4.63	8.85	13.50
180.	.98	9.48	15.05

dB (meters^2) for the aircraft in this thesis and listed as an intercept angle.

J/S can be determined by the following formula:

$$(J/S) = \frac{R^2 (4\pi)(ERP)}{P_t G_t \sigma_{RCS}} \tag{18}$$

where all terms are as previously defined (Ref 9:101-102). Converting all terms in equation (18) to dB equivalents yields:

$$(J/S)_{dB} = 2(R)_{dB} + (4\pi)_{dB} + ERP_{dB} - P_{t_{dB}} - G_{t_{dB}} - \sigma_{RCS_{dB}} \tag{19}$$

For a particular aircraft/SAM engagement, the terms 4π, ERP, P_t, and G_t are constant and the J/S ratio becomes:

$$(J/S)_{dB} = 2(R)_{dB} - \sigma_{RCS_{dB}} + K \tag{20}$$

where $K = 4\pi + ERP - P_t - T_t$.

The J/S required for equation (17) is obtained by converting the dB equivalent back to the actual value, or:

$$(J/S) = 10^{(J/S)_{dB}/10} \tag{21}$$

From equation (17), a smaller value of (J/S) results in a smaller CEP. The radar attempts to control (J/S) by insuring the missile impact occurs at the minimum

possible range from the site and the largest value of RCS. Both values can be achieved simultaneously when the missile impacts near the aircraft as the aircraft nears its closest approach point, R_C, to the site or the aircraft comes abeam the site. Here, the intercept angle is 90 degrees and from the values of RCS in Table V, RCS is a maximum. The launch rule for the radar sites in this thesis will be to attempt a launch when the intercept with the target occurs at the closest approach point to the site. This firing methodology is similar to the constant bearing intercept discussed by Breuer (Ref 3:166-173). A constant bearing intercept provides the shortest duration trajectory for a constant velocity target.

For a dry aircraft, CEP can be evaluated as follows:

$$CEP = \sqrt{D \frac{R^6}{\sigma^2_{RCS}} + E \frac{R^4}{\sigma^2_{RCS}} + F} \qquad (22)$$

where D, E, and F are constants dependent on the type of SAM and all other terms as previously defined.

The σ_{RCS} required in equation (22) is the one obtained by converting the dB equivalent to the actual values, or:

$$\sigma = 10^{\sigma_{dB}/10} \qquad (23)$$

Again, the lowest CEP and the highest P_k result when the intercept range is a minimum and the RCS is a maximum. For both wet and dry aircraft, the same launch decision rule will be applied: attempt to launch so that intercept occurs at 90 degrees angle between the aircraft's flight vector and the site's bearing to the aircraft (point C in Figure 11).

Intercept Geometry

At the completion of acquisition and tracking the model evaluates the specific encounter conditions between the threat radar and an aircraft. During acquisition and tracking the site determines the aircraft's heading, H, velocity, V_a, and both its slant range, SR, and bearing from the site. For each encounter two major areas dictate the intercept computations. Figures 10 and 12 depict these conditions. Based on its position, velocity, and heading the aircraft is located either prior to or past the closest approach point to the site, C. Within the first case (prior to the closest approach point) two possible conditions exist: the missile if fired immediately at the end of acquisition and tracking will intercept the aircraft at or prior to the closest approach point, or the missile will intercept the aircraft past the closest approach point. Referring to Figure 10, an aircraft at point A is headed in a direction such that its closest

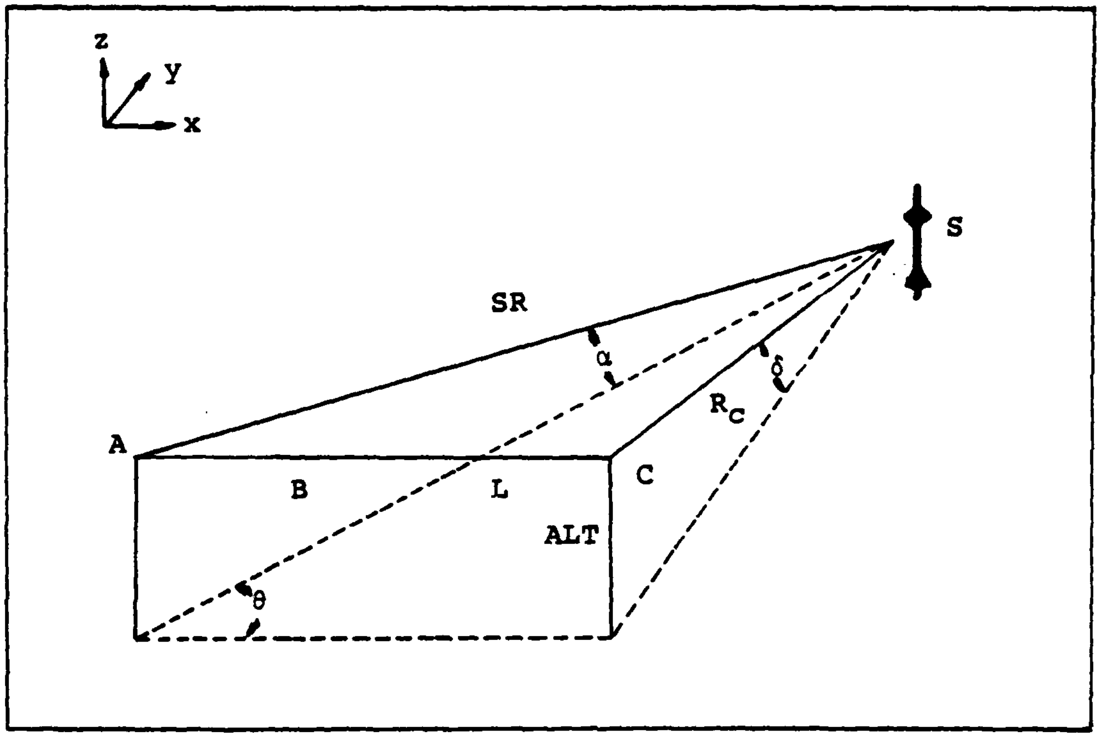

Fig. 10. Aircraft Prior to Closest Approach Point (3-Dimension)

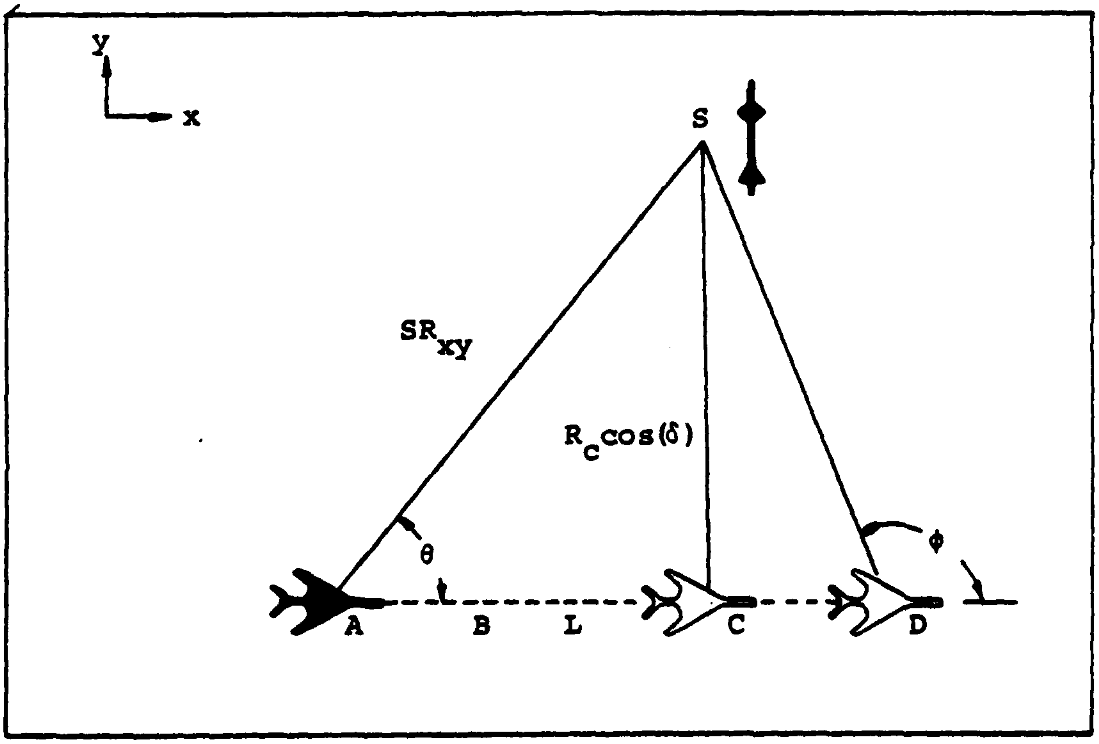

Fig. 11. Aircraft Prior to Closest Approach Point (2-Dimension)

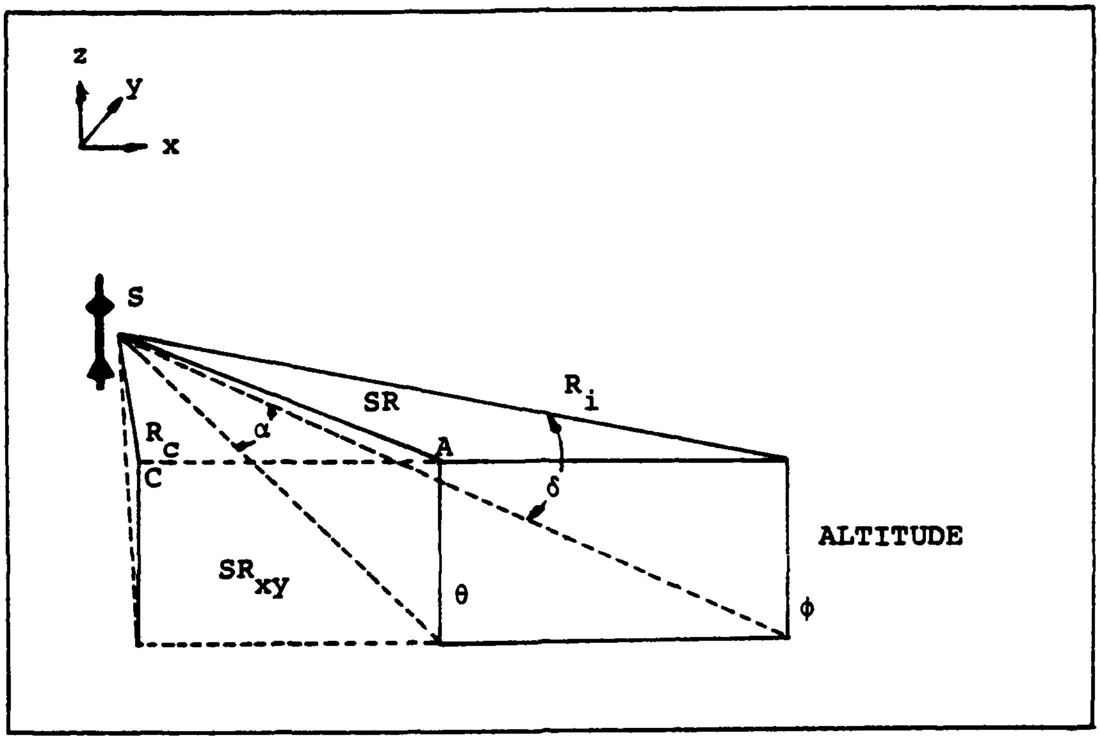

Fig. 12. Aircraft Past Closest Approach Point (3-Dimension)

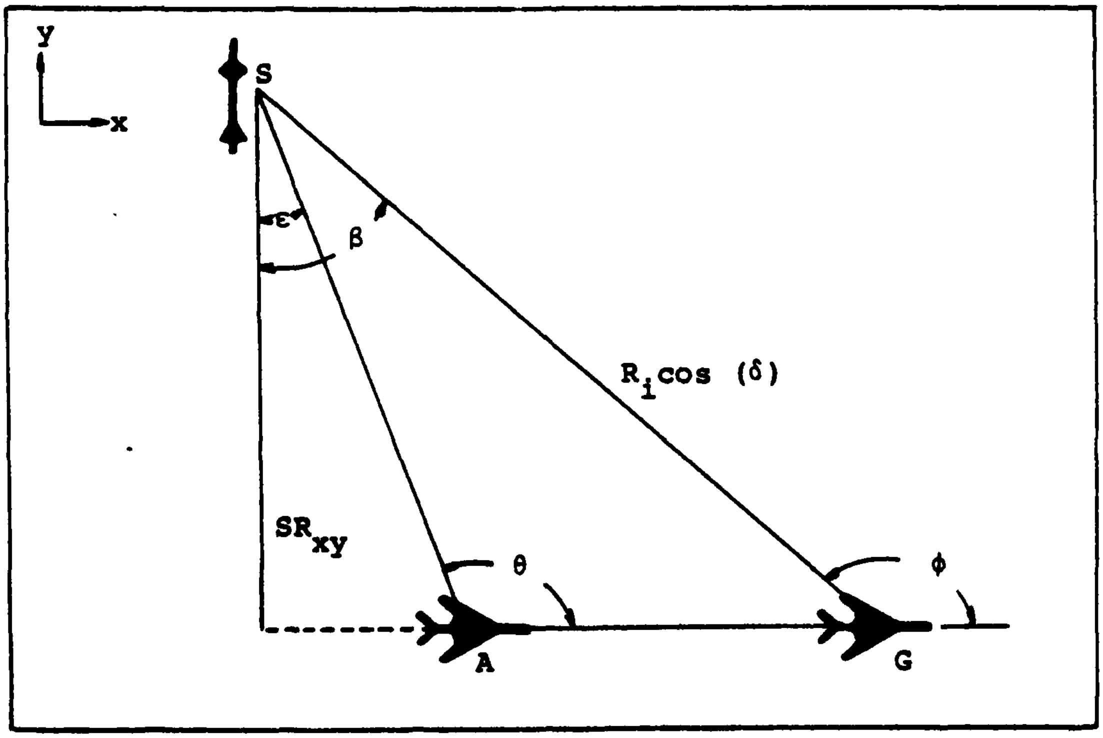

Fig. 13. Aircraft Past Closest Approach Point (2-Dimension)

approach to the site S occurs at point C. The slant range from the site to the aircraft, SR, is known (see equation (14)). The SR is projected down to the x-y plane as follows (see Figure 11):

$$SR_{xy} = SR \cos \alpha \tag{24}$$

where SR_{xy} = the projection of SR in the x-y plane, and all other terms as previously defined.

Using the bearing from the site to the aircraft and the aircraft's H, the angle θ is calculated. The time for the aircraft to reach point C, t_{AC}, is calculated as follows:

$$t_{AC} = \frac{AC}{V_a} = \frac{SR_{xy} \cos \theta}{V_a} \tag{25}$$

where AC = the length of the leg from A to C or SR cos θ,

V_a = the aircraft's velocity, and

all other terms as previously defined.

The time required for the missile to get from S to C, t_{MC}, is also known:

$$t_{MC} = \frac{SC}{V_m} = \frac{\sqrt{(SR_{xy} \sin\theta)^2 + ALT^2}}{V_m} \tag{26}$$

where SC = distance from point S to point C,

V_m = average missile flyout velocity, and

all other terms as previously defined.

Note: For a strike aircraft with a constant H, the R_i depends only on the difference between the site's and the aircraft's y coordinates, Δy, and the aircraft's altitude, ALT:

$$SC = \sqrt{ALT^2 + (\Delta y)^2} \quad (27)$$

where all terms are as previously defined.

The model now compares t_{AC} and t_{MC}. If $(t_{AC} > t_{MC})$ the missile, if fired now, would arrive at point C before the aircraft. Since the intercept must occur at C to achieve the lowest CEP, and highest P_k, a delay of $(t_{AC} - t_{MC})$ time units is programmed into the missile's firing schedule, resulting in both missile and aircraft arriving at point C simultaneously.

If $(t_{MC} > t_{AC})$ the missile, if fired now, would arrive at C after the aircraft. In this case, the intercept will occur past the optimum 90 degree intercept point. The new intercept point, D, can be calculated as follows:

$$CD = (t_{MC} - t_{AC})V_a \quad (28)$$

where CD = the distance past point C the intercept will occur, and

all other terms as previously defined.

The actual range to intercept, R_i can be calculated as follows:

$$R_i = \sqrt{CD^2 + (SR_{xy} \sin\theta)^2 + ALT^2} \tag{29}$$

$$t_{MD} = \frac{R_i}{V_m} \tag{30}$$

where t_{MD} = time of the missile to flyout to point D, and all the terms are as previously defined.

Instead of the RCS angle being an optimum 90 degrees, it will be a new angle, ϕ, where ϕ can be calculated as follows (see Figure 10 and 11):

$$\delta = \sin^{-1}\left(\frac{ALT}{R_i}\right) \tag{31}$$

$$\gamma = \cos^{-1}\left(\frac{CD}{R_i \cos\delta}\right) \tag{32}$$

$$\phi = 180 - \gamma \tag{33}$$

where all terms as previously defined.

Thus, the P_k can be calculated with CEP determined by the RCS for an aspect angle ϕ and the intercept range, R_i.

At this time the site, knowing the expected P_k, would evaluate its decision to fire. If the P_k is above some threshold value, the decision would be made to fire; if below, the site would be released from this threat and resume searching for another target aircraft. The

threshold value depends on other criteria such as the number of missiles available for firing and the priority placed on destroying the strike force/WW aircraft. For FEBA engagements early in a conflict with high stockpile levels of missiles, this threshold value will be low. For this thesis, P_k values above .05 will be considered adequate to warrant the site firing at the aircraft. Leek and Schmidt used an even lower threshold value of .02 in the firing logic of their thesis (Ref 9:50). If the P_k is above the threshold value, the missile is launched immediately with intercept occurring t_{MD} time units later.

The second major category of target is one already past the closest approach point at the completion of tracking and acquisition. Again, the site has determined the SR and bearing from the site plus the aircraft's H and V_a. (See Figure 12 and 13, page 49.) The range to missile intercept can be calculated as follows. The intercept will occur at a point, B. The time for the aircraft to get from its present position, A, to the intercept point, t_{AB}, will be the same as the time required for the missile to go from S to B, t_{MB}, or:

$$t_{AB} = \frac{AB}{V_a} \tag{34}$$

$$t_{MB} = \frac{R_i}{V_m} \tag{35}$$

and $$AB = \left(\frac{V_a}{V_m}\right) R_i = V_r R_i \tag{36}$$

where V_r = the velocity ratio, V_a/V_m, and all other terms are as previously defined.

For small angles, δ, $R_i = R_{i_{xy}}$, where δ is defined as follows (see Figure 12):

$$\delta = \sin^{-1}\left(\frac{ALT}{R_i}\right) \tag{37}$$

$$R_{i_{xy}} = R_i \cos \delta \tag{38}$$

where all terms are as previously defined.

The distance, R_i, can be determined using the Law of Cosines:

$$R_i^2 = (SR \cos \alpha)^2 + (AB)^2 - 2(SR \cos \alpha)(AB) \cos \theta \tag{39}$$

where all terms are as previously defined.

The angle θ is determined because the aircraft's heading and its bearing from the site are both known. Substituting from equation (36) for AB, equation (39) becomes:

$$R_i^2 = (SR \cos \alpha)^2 + (V_r R_i)^2 - 2(SR \cos \alpha)(V_r R_i) \cos \theta \tag{40}$$

where all terms are as previously defined.

Rearranging terms, the equation becomes a quadratic in R_i^2. Equation (40) is solved by the quadratic formula with:

$$a = 1 - V_r^2$$

$$b = 2(SR\cos\alpha)\ (V_r)\cos\theta$$

$$c = -(SR\cos\alpha)^2$$

$$R_i = \frac{-b \pm\sqrt{b^2 - 4ac}}{2a} \qquad (41)$$

The negative of the term under the radical is neglected since R_i is a positive number. The RCS angle at intercept can be determined since the bearing to the target, β, and the target's heading is known at intercept.

$$R_c = SR_{xy}\cos\varepsilon \qquad (42)$$

$$\beta = \cos^{-1}\left(\frac{R_i}{R_c}\right) \qquad (43)$$

$$\gamma + \beta = 90° \qquad (44)$$

$$\phi_{RCS} = 180 - \gamma \qquad (45)$$

$$\phi_{RCS} = 90 + \beta \qquad (46)$$

Again, knowing R_i and the RCS aspect angle ϕ, the CEP and P_k can be evaluated at intercept. Similar to the cases prior to the closest approach point P_k is above the .05

threshold value, the missile is fired. Because the intercept is beyond the closest approach point, the missile is fired immediately and intercept occurs t_{MB} time units later.

An additional consideration necessary before leaving the SAM attack geometry calculations is the necessity of the calculations to handle a maneuvering aircraft. The initial P_k evaluation at the end of acquisition and tracking was made considering the aircraft's heading to be constant. Since the WW aircraft can maneuver, this may not be true. To account for a turning possibility this thesis incorporates the following modification. At the scheduled missile firing time, a new R_i is calculated (see equation (29) or (41)). If the $R_{i_{new}}$ is the same as the initial R_i calculated at the end of acquisition and tracking, the aircraft has not turned and the intercept will be the same. To preclude small variations in the R_i calculations, a .1 tolerance is allowed, or, intercept will be considered the same if:

$$(.9\ R_i \leq R_{i_{new}} \leq 1.1\ R_i) \tag{47}$$

If $(R_{i_{new}} < R_i)$, the aircraft must have turned toward the site. A new ϕ and P_k are calculated and a new launch time computed based on the $R_{i_{new}}$. A new launch time is computed using the above calculations (equations (25)-(26))

and a new launch time is schedule. If ($R_{i_{new}} > R_i$), the new P_k is evaluated. If the P_k is above the .05 threshold value, the site immediately fires the missile and computes a scheduled impact time.

At the scheduled impact time the R_i is again compared to the value computed at the missile launch time. If both the R_i values are the same, the P_k can be evaluated. If the new R_i is less than the launch R_i, the aircraft has turned towards the site. The P_k and ϕ are evaluated at the new R_i. If the new R_i is greater than the launch R_i a new impact time is scheduled. This new impact time is

$$t_i = \left(\frac{R_{i_{now}}}{R_{i_{launch}}}\right)\left(\frac{R_{i_{launch}}}{V_m}\right) \tag{48}$$

or

$$t_i = \frac{R_{i_{new}}}{V_m} \tag{49}$$

where all terms are as previously defined.

At the new impact time, the same calculations are made and the P_k reevaluated. In this manner, the flight time of the missile can be approximated without requiring a separate missile flyout time routine as part of the thesis.

Differences with Previous Modeling Efforts

The SAM engagement portion of this thesis differs from the approach used by Leek and Schmidt. In their model, Leek and Schmidt assumed that if the attack aircraft maintained a 20 dB J/S ratio at the radar the site was denied the ability to track in both range and azimuth. Using this criteria, kill zones in which the J/S dropped below 20 dB for the particular SAM were established. If the aircraft passed through this kill zone at the scheduled impact time the P_k was calculated. If the aircraft intercept occurred outside the zone, the P_k was set equal to zero. To this end the Leek and Schmidt model attempted to control the SAM launches such that, if possible, launches were delayed so that intercept occurred when the aircraft entered a kill zone. The kill zone criteria resulted in a narrow azimuth window near the 90 degree relative bearing to the site (Ref 9:24-31).

The main criticism is that this approach does not consider even the most rudimentary electronic counter countermeasures (ECCM) techniques. Most modern SAMs employ some type of ECCM such as frequency discrimination, side-lobe blanking, or polarization mismatch to defeat ECM techniques. Although not explicitly stated, attack aircraft in the Leek and Schmidt model used noise jamming. This type of jamming normally denies range information to a site

although angle information can be obtained since the output from the noise jammer results in a strobe on the radar scope of the site eminating from the azimuth of the target aircraft. In this case, a network of sites such as the model employs could triangulate and to determine the aircraft's approximate location (Ref 15:547-550). For this reason kill zones are not defined. Instead, a necessary assumption in the analytical portion of the model is that the sites use some type of ECCM techniques and the aircraft's P_k is based on the calculated value of CEP, R_i, and σ_{RCS} determined in the above equations, not whether the aircraft at missile impact falls in a kill zone. For large values of R_i and high CEPs an appropriate decrease in P_k will be calculated as per equations (17) and (22).

AAA Probability of Kill

The AAA P_k calculations follow closely the work of Leek and Schmidt (Ref 9:35-40). The short maximum engagement range of the AAA (2990 m, see Table IV) means the aircraft must pass near the site before being attacked. The P_k calculations are based on the vulnerable surface area of the aircraft as a percentage of total surface area as viewed from a specific aspect angle, the dispersion of the AAA rounds around the actual aim point, the time of flight (TOF) of each round from the gun to target, and the number of rounds fired in each engagement.

The projectile's TOF is a function of the initial and final velocity of the projectile. The velocity of the round at impact, V_f, can be determined as follows:

$$V_f = V_i \exp[-\rho C_d A R_i / 2m] \tag{50}$$

where V_i = the initial muzzle velocity of the round, m/sec (930);

ρ = density of the air, kg/m^3 (1.2247);

C_d = dimensionless coefficient of drag (.38);

A = cross-sectional area of the round, m^2 (4.16 x 10^{-4});

R = intercept range, km; and

m = mass of the round, kg (.195) (Ref 3:48).

Substituting the average values used in the calculations (in parenthesis, above) the equation reduces to the following in terms of R kilometers to intercept:

$$V_f = 930 \exp[-.4965\ R_i] \tag{51}$$

From the velocity calculation, the TOF, in seconds, can be determined:

$$TOF = \frac{2m}{\rho C_d A}\left[\frac{1}{V_f} - \frac{1}{V_i}\right] \tag{52}$$

where the terms are as previously defined (Ref 3:48).

Substituting the average values from the above equation this becomes:

$$TOF = \frac{2014.46}{V_f} - 2.166 \qquad (53)$$

Leek and Schmidt use an average vulnerable area (A_v) of 55.65 ft^2 (5.17 m^2) (Ref 9:39). This was based on an average viewing aspect of a total projected area of 265 ft^2 and a 21 percent vulnerable area.

The dispersion of the rounds about the aim point in a combat situation was assumed to be 20 mils (Ref 9:39). This angular dispersion represented a one sigma standard deviation. Figure 14 depicts the angular deviation σ in terms of R. Converted to range at intercept, the σ becomes:

$$\sigma_m = \sigma R \qquad (54)$$

where R = intercept range, km;

σ = angular deviation, in mils;

or

$$\sigma_m = 20R \qquad (55)$$

The single shot probability of kill ($P_{k_{ss}}$) becomes:

$$P_{k_{ss}} = \frac{A_v}{2\pi\sigma^2 + A_v} \exp\left\{- \frac{1}{2}\left[\frac{[9.8\ g\ TOF^2]^2}{2\pi\sigma^2 + A_v}\right]\right\} \qquad (56)$$

where g = the number of "g's" the aircraft is undergoing for its current position in the battle area (Ref 13:98).

Sustituting the constant terms the equation becomes:

$$P_{k_{ss}} = \frac{5.17}{2\pi\sigma^2 + 5.17} \exp\left\{- \frac{1}{2}\left[\frac{[9.8\ g\ TOF^2]^2}{2\pi\sigma^2 \div 5.17}\right]\right\} \qquad (57)$$

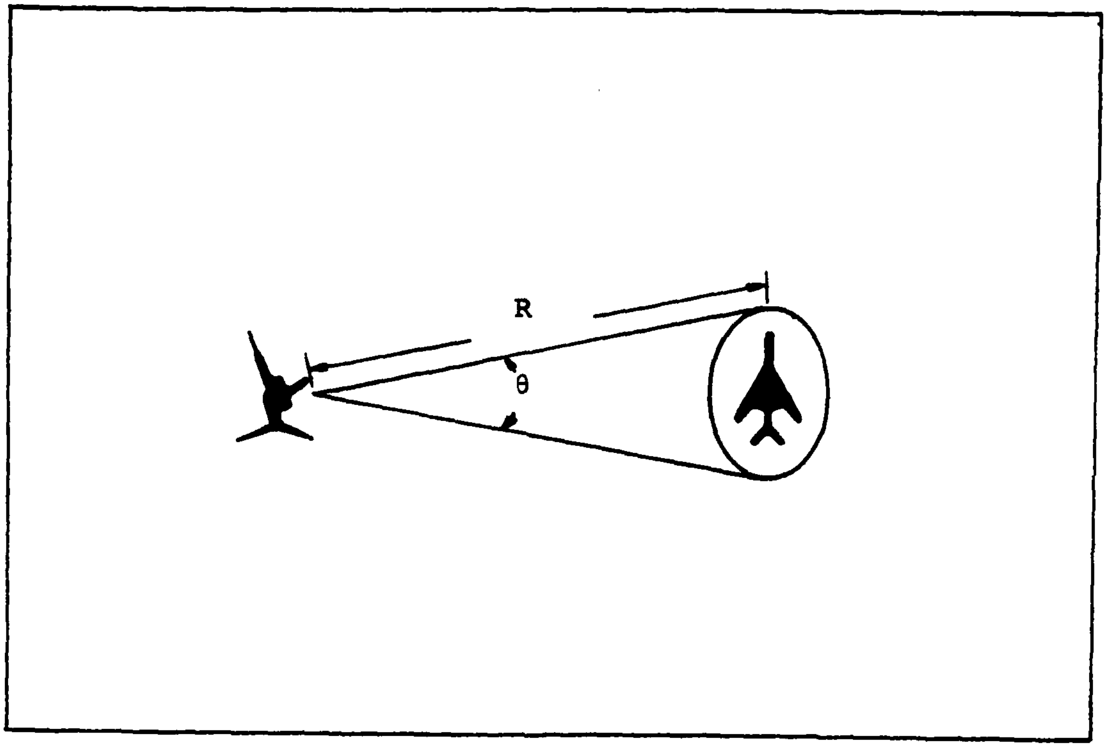

Fig. 14. AAA Dispersion Pattern

The overall P_k is dependent on the $P_{k_{ss}}$ and the number of rounds, n, fired by the AAA. Fifty rounds would be typical for the combat arena: adequate to cover the target, yet not enough to overheat and damage the gun barrels. For the AAA weapons of the model, this represents a 2/3 second burst. Finally, the P_k calculation becomes:

$$P_k = 1.0 - (1-P_{k_{ss}})^{50} \qquad (58)$$

or the probability of AAA kill, P_K, is 1 minus the probability of the aircraft surviving 50 single round shots (Ref 9:39).

Command and Control

The Soviets employ numerous EW radars to augment the command and control of the air defense behind the FEBA. This thesis portrays command and control of threat radars by associating EW radars with randomly selected weapon system radars. The EW sectors are defined in terms of threat belts and the LOC. The EW radars and their assigned coverage sectors are shown in Figure 15. EW radars depicted in the figure as an $\overset{Nn}{\boxed{X}}$ are used for area control of radars located in sector "n" and control all systems types within that sector. An EW radar depicted as $\overset{w}{\boxed{X}}$ is associated with a specific weapon system battery.

Area 1 extends from the FEBA to belt 5 (five kilometers behind the FEBA) and north of the LOC (see Figure 1). Area 2 covers the same east-west distance south of the LOC. Area 3 extends from belt 5 to belt 9 (35 kilometers behind the FEBA) and north of the LOC. Area 4 covers south of the LOC and below area 3. Area 5 extends east from belt 9 to the target area, covering both north and south of the LOC.

Each of the area specific EWs provides early warning information for threat batteries located within its area. By attacking the EW radars the WW can disrupt the normal handoff communication between the EW and its associated threat radars, thus increasing the time required by

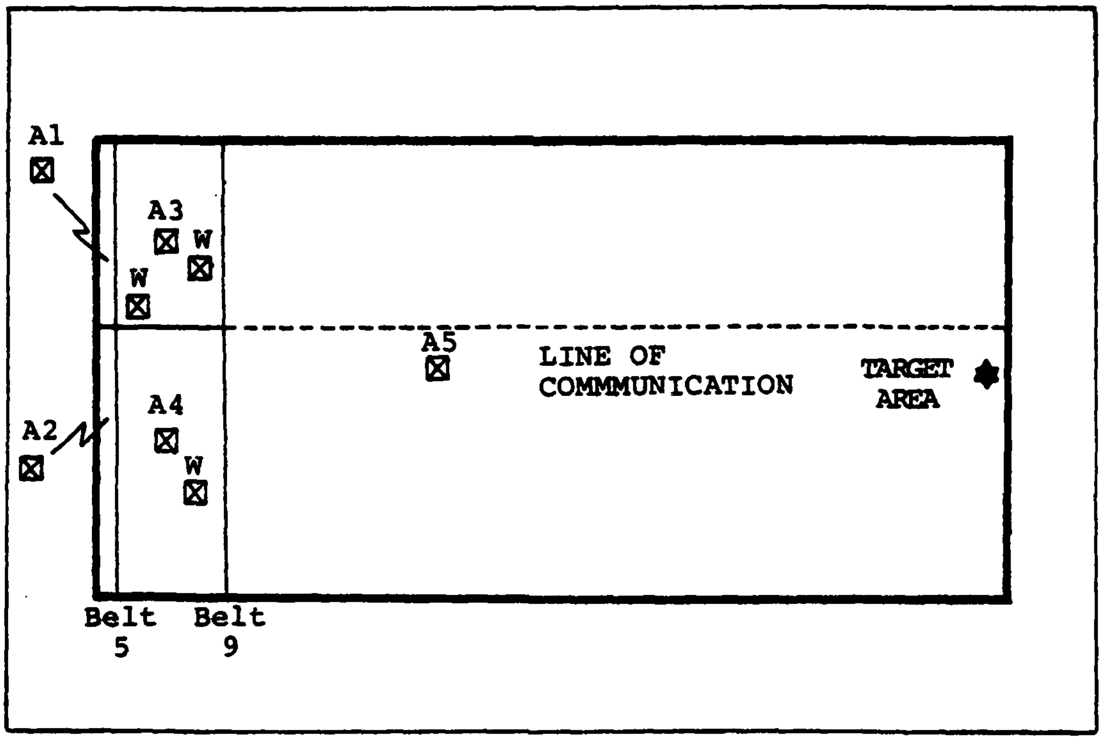

Fig. 15. Early Warning Network

individual sites to acquire, track and fire on an aircraft.

The threat environment of this model associates 50 percent of each threat type radars with a specific area EW radar. (Note: The Soviets have many types of EW systems. This thesis models a general system associated with only a percent of the total threat radars.) For example, half of the threat radars in area 1 are assigned to N1 $\boxtimes$. If the WW kills this EW radar or forces it to stop radiating, those radars associated with it must operate autonomously and the corresponding target acquisition and tracking time will be at a maximum value. The remaining threat radars

that do not have an associated EW in the model will be assumed to have acquisition and tracking times uniformly distributed between a minimum and maximum value.

Summary of the Defensive System Structure

The WW and strike aircraft attempt to penetrate an enemy defensive structure comprised of four types of SAMs, one AAA weapon system, and an EW radar network. The enemy weapon systems attempt to engage the aircraft as soon as possible and evaluate the probability of destroying the target. System characteristics such as maximum detection range and minimum detection altitude limit the distance at which an aircraft can be detected. After detection the radars track the targets for a specified time. The duration of this acquisition and tracking time depends on whether or not the site received track information on the aircraft from an EW site. During this time period the site calculates the aircraft's heading, velocity, and both the slant range and bearing from the site.

The sites attempt to launch a missile or fire on the aircraft so as to maximize the P_k. P_k calculations for SAMs depend on the range to intercept, R_i, the aircraft's RCS at intercept, and the weapon's lethal radius. AAA P_k depend on the TOF of each round, the dispersion pattern of rounds about the target, the target's vulnerable surface area, and the number of rounds fired at the

aircraft per engagement. If the weapon's estimated P_k is greater than a 5 percent threshold value the site will launch at or fire on the target.

The model also provides a method for evaluating launch and impact/intercept times for maneuvering targets. At the end of acquisition and tracking the model calculates a range to intercept, R_i, at the launch time. When the simulation time reaches this scheduled launch time the model recalculates and compares this new R_i to the one calculated at the end of acquisition and tracking. If the two values compare within 10 percent, the site launches its missile. If the two differ a new launch time is scheduled. In a similar manner, the R_i at impact/intercept is calculated and compared to the one computed at launch. If the two differ by more than 10 percent, the impact/intercept is rescheduled.

Summary

The chapter described each of the three major elements comprising the FEBA penetration air battle and developed the analytical methodology of the interaction between the three elements. In the next chapter this methodology will be translated into a simulation model.

III. Simulation Model

Overview

In the previous chapter the components and characteristics of the WW defense suppression system were described and the system structure defined. Once this has been done the model can be computerized. In this chapter the structural model is translated into the SLAM simulation language. First, simulation models are reviewed with emphasis on the two basic timekeeping orientations. Next, the SLAM language is introduced and the interfaces with the structural model are covered. Finally, the simulation model is presented in a logical, sequential manner.

Simulation and Combined Simulation Models

Simulation modeling was chosen as the methodology to analyze the WW defense suppression problem because there were no analytical methods available that could represent the dynamic interactions and extreme complexities of WW operations. In addition, it would be very difficult if not impossible to conduct an experiment with the necessary system components of the WW defense suppression mission. Simulation modeling offers a viable alternative for analyzing the WW system.

Simulation modeling is a technique for studying problems in which a model of the problem is constructed resembling the system under investigation. After the model is developed experiments are conducted over the time period of interest simulating the operation of the system. Data are then gathered to estimate the characteristics of the problem.

Models can be classified as either discrete change or continuous change systems. The basic difference between the two systems is the manner in which system time is modeled. In discrete change simulations system variables change only at specified points in simulation time. These points are commonly called event times. An example of a discrete change system is a bank where the number of customers in the bank changes only when a customer arrives or departs. In continuous change simulations the system variables continuously with time. An example is an airplane in flight. Because the variables change continuously over time differential equations are required to define the relationships between the variables.

Real systems are neither discrete nor continuous but a combination of both. In a combined discrete-continuous simulation there are three types of interactions that can occur:

1. A discrete event may cause a discrete change in the value of a continuous system variable.

2. A discrete event may cause the relationship governing a continuous system variable to change at a particular time.

3. A continuous state variable achieves some predetermined value (threshold value) which may cause a discrete even to occur or be scheduled (Ref 8:47).

The conceptual framework for the combined model is that the system can be described in terms of entities (such as airplanes or radar systems), their attributes (which are characteristics of entities such as velocity and altitude for an airplane or minimum and maximum effective range for a radar system), and state variables (which are the continuous system variables that change with time such as an airplane's position in flight). The behavior of the system is simulated by computing the values of the state variables at small time steps and by computing the values of attributes of entities at event times (Ref 12:72). In combined simulations, events can occur at a scheduled point in time or when the system reaches a certain state. An example of the former is when an aircraft is detected by a radar system. Its exact position can only be determined after a given time interval, representing the radar's tracking and acquisition time. In a simulation, this event would be scheduled to occur. An example of an event occurring when the system reaches a certain state is when a WW searches for a threat radar to attack. As the WW proceeds

across the defense area, its position continuously changes. As its position changes, its line-of-sight distance and the distance to the nearest available radar that the WW can attack are compared. As the line-of-sight distance crosses the distance to the nearest available radar, a state event is defined to have occurred: the radar has been detected by the WW. The possible occurrence of a state-event must be tested at every simulation time advance.

SLAM and Structural Model Interfaces

The WW defense suppression system, as described in the structural model presentation in Chapter II, consists of three entities--WW aircraft, attack aircraft, and threat radars. The attributes of the aircraft can be considered the following: call sign, velocity, altitude, ARM configuration (WW only), turn rate (WW only), radar cross-section, and heading. The attributes of the radar are its sequential number, minimum effective altitude, maximum effective range, associated EW radar (if any), power configuration, and position. The state variables for the system are the attack aircraft's position and the WW's position, heading, velocity components, distance to the attacked radar, line-of-sight distance, relative and absolute relative bearing to the attacked radar. Note that the concept of a state variable is dependent on the viewpoint of the modeler.

As previously noted, continuous modeling involves characterizing a system's behavior through a set of time-dependent equations (Ref 12:62). The WW's position and heading are described by a set of such equations. Figures 16 and 17 depict how the model solves for the aircraft's position over each small time increment. In Figure 16, an aircraft is located at point A with an x and y coordinate (x_1, y_1) and a heading H. The aircraft's velocity vector, $\bar{v}$, at point A can be resolved into two components, V_x and V_y. An increment of time Δt later, the aircraft is located at point B (x_2, y_2). The model solves for the value of the new coordinates as follows:

$$x_2 = x_1 + \bar{v}\ \Delta t \tag{59}$$

$$x_2 = x_1 + (V \cos \theta)\ \Delta t \tag{60}$$

Similar evaluations of the y components of heading allows the aircraft to "fly" across the battle area.

The SLAM simulation language was chosen for this problem because of its power and flexibility to incorporate a combined simulation model necessary for the WW defense suppression mission. The many dynamic interactions and inherent complexities of the WW system required a language that was capable of representing model processes in a simple and direct manner.

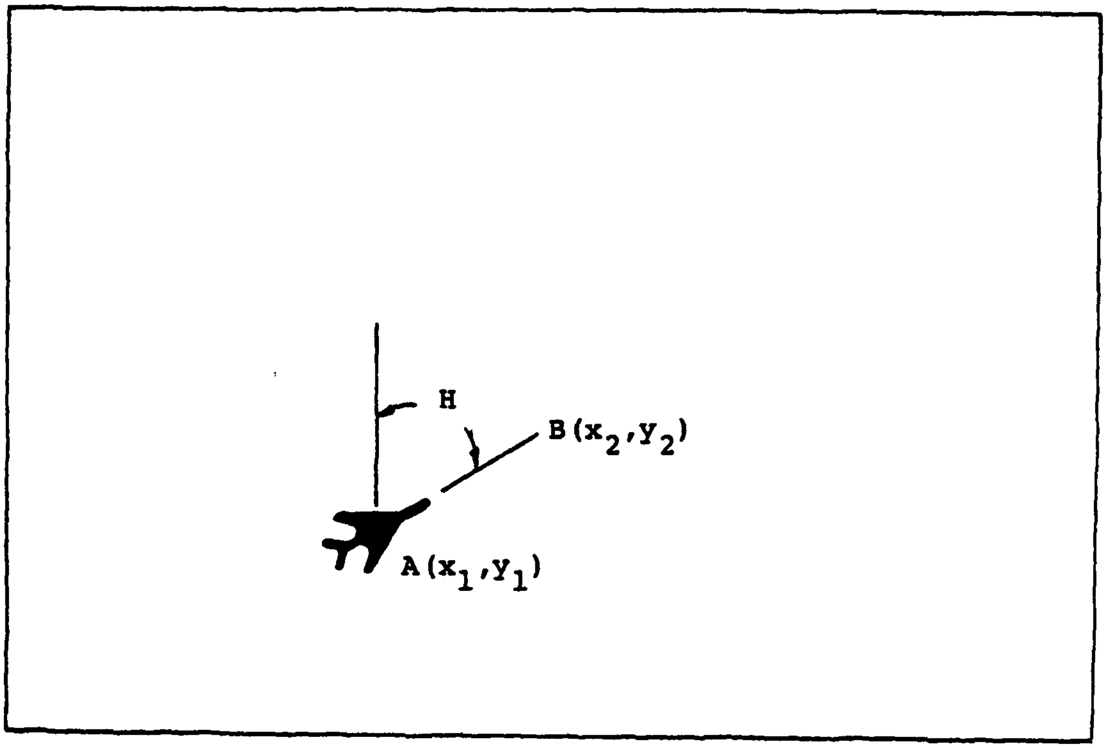

Fig. 16. Continuous Model Diagram

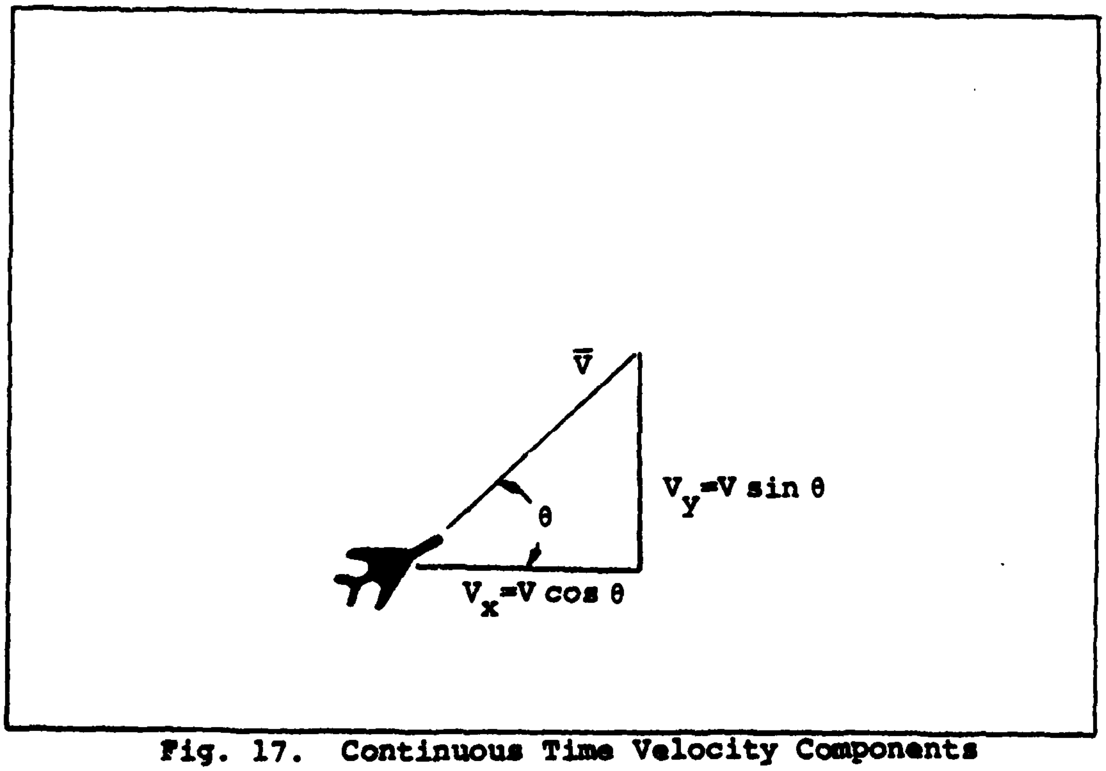

Fig. 17. Continuous Time Velocity Components

In the WW structural model, aircraft fly through the defense area enroute to the target area (attack aircraft) or fly through the area in pursuit of threat radars to attack (WW). SLAM portrays this process of entities flowing in a system by employing the concept of a network structure. The network consists of special symbols called nodes and branches. These symbols model elements in the WW system where an activity (branch) or an event (node) could be realized. The network is essentially a pictorial representation of the system. The use of a network structure to describe the system structure is especially helpful to the modeler in getting the "whole idea" concept of the model.

Aircraft (entities), therefore, are modeled as flying through the defense area where processes occur. The processes that aircraft undergo are attack by threat radars or, in the case of the WW, attack on the WW by threat radars and the WW attack on the threat radars.

SLAM incorporates discrete change simulation by allowing the modeler to define an event and the changes that occur in the system at discrete points in time. The time where the state of the system changes is called an event time and the associated logic for processing the change is called an EVENT in the SLAM notation. The WW attack profile logic is modeled using events, specifically events 1 through 13. See Appendix A.

The interface between the network, discrete event, and continuous models is crucial in modeling discrete-continuous change systems. Continuous change variables interact with discrete change variables through a state-event. This mechanism is nothing more than an event which is triggered by a continuous state variable reaching a pre-determined value. The predetermined value is commonly called a threshold value.

The SLAM DETECT node is the primary interface between the network and continuous portions of the combined model and is used extensively in the WW attack profile. The duration that the WW is engaged in certain activities is keyed to the release of the appropriate DETECT node. For example, when the WW initially detects a threat radar a turn direction is computed for the WW as it begins its ranging routine on the threat (EVENT 1 in the simulation model). The duration or time the WW is in that turn is keyed to the release of a detect node (DETECT node W17 for WW1). When the continuous state variable, in this example the absolute relative bearing to the threat radar (state variable SS(49) for WW1), reaches the predetermined value of 75 degrees then the duration of the first ranging routine is completed and the WW reaches the next network node (EVENT 2 for the example). See Appendix A for the SLAM network.

SLAM incorporates numerous modeling mechanisms to assist the modeler in translating the system into the simulation model. These mechanisms are invaluable tools for not only making the computerization of the model straightforward but also for helping crystalize a system's complex interactions into clear and simple programming. The more important mechanisms are presented in the following paragraphs while the remainder are discussed in the simulation model itself.

A simulation model is built for a specific purpose. Once the model is built system variables are changed to test various conditions of the model. The ease in which these variables can be changed is a test of the language's flexibility. SLAM incorporates the concept of a global variable (XX(i) in SLAM notation) to provide this flexibility. System variables such as aircraft altitude or velocity can be defined in the simulation model as global variables. The global variables can be changed to another value by the modeler in subsequent experimental runs of the model. For example, WW altitude is defined in the simulation model equal to global variable XX(3) (see Appendix A). For the first 5 experimental runs WW altitude is to 60 meters (XX(3)=60, see line 172 of the SLAM program in Appendix A). For the following 5 experimental runs, altitude is changed to 200 meters (XX(3)=200, see line 178 of the SLAM program). The ease and efficiency of changing

system variables in this manner demonstrates the power and flexibility of SLAM.

Entities are generated in the model and routed through the network by CREATE nodes. At these nodes, the time of an entity's first creation, the time between entity creations, and the number of entity creations are specified. For the simulation model two CREATE nodes are used, one for generating WWs and the other for attack aircraft.

Entities have unique characteristics associated with them which SLAM denotes as attributes. In the simulation model WW aircraft have two explicit attributes: call sign (211 or 212) and ARM configuration. These attributes flow with their respective entities in the network. SLAM designates attributes at ASSIGN nodes. In the model ASSIGN node WAS prescribes attributes for the WW and ASSIGN node AAS for the attack aircraft.

Simulation Model

The WW-threat environment system structure was modeled into the SLAM network and is shown in Appendix A. The network can be considered to be in two parts: a WW attack network, where the WW hunts for threats to attack; and a radar attack network, where threat radars attack aircraft flying through the defense area.

Two WWs enter the engagement through the CREATE node with the time between arrivals specified as global

variable XX(8). The WWs enter the conflict area 50 km prior to the FEBA to allow sufficient time to search for threats. The WW's attributes are specified in the ASSIGN node WAS. Attribute one is the WW's tail number (211 or 212) and attribute two is its ARM allocation. The first digit of attribute two indicates the number of AGM- Bs and the second digit the number of AGM-As. Each WW enters the area ±500 meters of the centerline that divides the area into equal north and south components.

The attack force aircraft are created at the second CREATE node with time between creations equal to XX(7). A total of ten attack aircraft are created. As with the WWs, the attack force enters the area 50 km prior to the FEBA. Attribute one for the attack force is assigned at node AAS and represents the call sign of the aircraft (1 to 10). The attack force also enters ±500 meters of the FEBA centerline.

WW-Attack Profile

Continuous modeling concepts are used to simulate the WW-attack profile of the model. This essentially involves characterizing the behavior of the WW to a system of equations. As the status of the WWs change in the system, the equations that describe the WW also change.

After the WWs are created they are separated at node G1 based on their tail number and go to either

GW1 or GW2. (All aircraft are routed to node RATK for the radar-attack phase of the model. This network will be described later in the chapter.) Each WW is then routed through a sequence of events determined by whether certain conditions are detected by key model parameters. These conditions roughly correspond to the phases in the structural model. The network phases are identical for each WW.

At node G1, WW1 begins an activity. The duration of the activity from node G1 to node RN1 is specified as REL(W1S). REL is a release specification and it is used throughout the WW-attack portion of the network. When the node upon which the release specification is realized, in this case node W1S, then the activity is completed. Thus, the time it takes for WW1 to get from G1 to RN1 is keyed to the release of node W1S. W1S is a DETECT node whose condition for release is that the range of WW1(SS(37)) decreases to less than WW1's radar line-of-sight (SS(41)). WW1 is held in the activity between G1 and RN1 until W1S is detected. Continuous state equations describe the WW's position as time advances and are explained in the paragraph on subroutine STATE. At each new iteration of time, the WW's position is changed and ranges to all candidate threat radars are evaluated. Finally, when the WW's range is less than the line-of-sight range, W1S is detected which in turn releases REL(W1S). WW1, along with its attributes proceeds to node RN1.

At RN1 event 1 is called (line 31). Event 1 turns the WW in the shortest direction to begin its triangulation routine on the radar. Turn rate for the WW is specified as RATE and is set to four degrees per second (simulating a 60° bank, level turn). The WW's working designator, SS(I+12), is set to 1 to key subroutine STATE from computing new threat parameters when the WW has just started to engage a radar. The radar the WW is attacking has its 14th attribute reset to the WW's call sign, replaced in File 2, and then copied into the WW's attack file.

WW1 now starts the activity from RN1 to RE1. The release specification for this activity is W17. W17 detects an absolute relative bearing (SS(49)) of 75 (degrees) and sends WW1 to event 2. Event 2 rolls the WW out of its turn (RATE=0). The next activity is begun and is keyed to detect node W10 which is realized when the WW's absolute relative bearing increases to 105. Upon detection, WW1 is sent to event 3 (lines 447-454) which now turns the WW back into the threat (RATE=±4 depending on turn direction). WW1 now waits until detect node W1T is realized which occurs when the aircraft is within 10 degrees relative bearing to the threat. When W1T is released event 4 is called (lines 455-464) which reduces the WW's turn rate to 2 degrees per second. Following event 4, WW1 begins an activity until detect node W1B is realized. This occurs when WW1's

heading (SS(29)) and relative bearing to the threat (SS(45)) are identical (aircraft boresighted on the radar).

Event 5 (lines 466-529) begins by selecting which ARM to fire. If the WW is too close to fire an ARM (range to threat is less than minimum range of the ARM) then the WW is sent back into the network for a "repositioning routine" (events 10 and 11). Otherwise, ARM firing range is determined based on minimum and maximum ranges of the ARM and the distance from the WW to the threat. Flight time of the ARM is computed based on ARM firing range and velocity. P_k is determined from a random sample draw. The time for the WW to get to the ARM release point is calculated (RLWW) and is loaded into XX(15) (XX(IR)). XX(16) is set equal to the ARM's flight time (TOF). The WW's turn rate is set to zero. The WW now re-enters the network.

Back in the network, WW1 can take one of two paths. If the WW is too close to fire an ARM (range to threat less than the minimum ARM range, SS(38) less than 800) then it begins a repositioning routine to place it in firing range and takes the branch to node WR2 with a release specification of WR2. (Repositioning routine network will be discussed later in the chapter.) Otherwise the WW takes the branch to event 6 with a duration specified as XX(15), the time to get WW1 to ARM release point.

At event 6 the WW launches an ARM. Each of the WW's four ARMs has its own TOF designator. For WW1, ARM

number one's TOF is set to XX(85), number two's to XX(86), number three's to XX(87), and number four's to XX(88). Thus the capability exists in the model to have a WW launch all four ARMS simultaneously. The TOF for each ARM is used to evaluate its respective P_k at impact time. This is accomplished by calling the appropriate ENTER node. For WW1 ENTER node 1 is called with the attributes of the radar being passed along to the ENTER node. After the WW is sent back to the network, a check is made to see if there are any ARMs remaining. If the WW is out of ARMs, then its working designator is set to nine to key subroutine STATE.

WW1 goes back to the network and can branch in one of two directions. If it no longer has any ARMs then the WW is sent to node WGH to begin a "go home routine." Otherwise, after a five-second delay to simulate release of the ARM, the WW goes to event 7. Here its working designator is set to zero to key subroutine STATE to select a new radar to attack. After a 0.1 second delay in the network, which allows STATE to select a new threat, event 8 is reached.

Event 8 enters the WW back into the network depending on its distance to the new radar. If the distance to the threat is less than line-of-sight range (for WW1, SS(37) less than SS(41)), then the triangulation routine is started, the WW's working designator set to one, a turn direction is computed, and the network is re-entered. If

the distance to the threat is beyond the WW's line-of-sight range then no activities are performed by the WW in event 8. When the WW returns to the network from event 8 it can take one of two branches. If the distance to the threat was less than its line-of-sight distance, then the WW branches to node RE1, with a release specification of W1C, absolute relative bearing passing 75. (Node RE1 is event 2 where the remainder of the triangulation routine is performed.) If the WW does not detect the new threat, which was selected by subroutine STATE as the closest threat to the WW, then the WW branches to node GW1, where it essentially begins the process of searching for threats to attack once more.

As described previously in the paragraph on event 6, when the WW launches an ARM, the appropriate ENTER node is called. The network for ENTER nodes one and two simulate the flight path of the ARM. At ENTER node one, the ARM can take one of four paths to node WRK depending on whether it is the first, second, third, or fourth ARM launched by WW1 (XX(17)=1,2,3, or 4). The duration of the activity for the ARM to get from the ENTER node to WRK is equal to the TOF of the ARM which was calculated in event 5 and set equal to the appropriate global variable (XX(85,86,87, or 88)).

At node WRK event 9 occurs which evaluates the P_k of the ARM. If the WW kills the radar, then the following

sequence of events takes place. First, if the radar was an EW radar (ATRIB(1)=1) then all threat radars associated with it have their 5th attribute set to 10 to key tracking and acquisition time computations, which are described in the radar-attack portion of the model. Next, the destroyed radar is removed from both the current radar file (File 1) and the WW available file (File 2). All events associated with this radar are removed from the event calendar. Finally, XX(49) is set to attribute one, the radar's sequential number in the model.

If the radar is not killed, then its 14th attribute is reset to zero to indicate that the radar is once again available for engagement by a WW.

From event 9 the ARM/WW will go to node WKL if the radar was killed. It then enters an assign node where XX(50) counts the number of radars killed by the WW.

If after the WW completes the triangulation routine and finds itself too close to fire an ARM due to the minimum range of the ARM (event 5) then a repositioning routine is started. This routine begins in event 5 which initially turns the WW away from the site after the range to the radar was determined to be too small to fire the ARM. From event 5 the network is entered and WW1 is sent to node WWR after waiting until node W1R is released, which occurs when the absolute relative bearing to the site is 179. This position places the radar at the WW's 6 O'clock

position as the WW attempts to get sufficient distance to fire its ARM. Node WWR is event 10 which rolls the WW out of its turn. From event 10, WW1 enters the network with an activity duration whose release specification is W1D. Node W1D is realized when WW1's range to the radar passes 18,000 meters. WW1 proceeds to event 11 where it is turned back into the site to re-attack. When WW1 is boresighted on the site (W1E), event 5 is reached once again where an evaluation for an ARM launch is made.

When the WW fires its last ARM it is sent back across the FEBA via node WGH, event 13, and node WHM. Global variable XX(48) counts the WWs as they reach the home point.

The network logic for WW1 and WW2 is identical. Each WW, however, has its own separate network where only activities that pertain to it can occur. The logic for the events that describe the WW-attack scenario are the same no matter if the aircraft is WW1 or WW2.

Radar-Attack Profile

In the radar-attack po'tion of the network threat radars engage both attack force and WW aircraft. As each aircraft enters the network the range to the closest radar that isn't tracking an aircraft is calculated. If the range is less than the maximum effective range of the threat radar, then a sequence of events is started that

simulates the profile for a threat system to launch a SAM or shoot a AAA at the target aircraft.

All aircraft, after they are created, proceed to node RATK, where event 14 is called. This event simulates the radar search phase of the system. If the aircraft has reached the target area then global variable XX(55) is set to the call sign of the aircraft to key the network and the event is terminated. Similarly, if there are five threats already engaged with the aircraft, then radars are not allowed to search for this particular aircraft and the event is terminated. If these two conditions are not encountered then subroutine SEARCH is called.

<u>Subroutine SEARCH</u>

Subroutine SEARCH simulates the actual threat radars searching for aircraft as they fly through the threat environment. When an aircraft enters SEARCH every radar is evaluated to determine if it can engage the aircraft. Four checks are first made to determine if the radar can engage the aircraft. If the radar is an EW radar or if the aircraft's altitude is below the radar's minimum altitude or if the radar is already engaged or if the radar is not operating; if any of these conditions are met, then the radar cannot engage the aircraft. If the radar passes these four checks, then the distance is greater than the multi-path range then the radar will be unable

to track the aircraft. Finally, if the distance from aircraft to radar is greater than the maximum effective range of the radar, then this too excludes the radar from tracking the aircraft. If the radar passes all of these checks then the model allows the radar to start the engagement sequence. The radar's 8th attribute is set to the aircraft's call sign, the radar, along with its attributes, are filed in the radar aircraft file (LF), the radar, with its new 8th attribute, is copied back into File 1, and an acquisition and tracking time is computed. This time, TRC, is computed from a uniform distribution based on the threat radar's minimum and maximum acquisition time unless the threat radar's associated EW radar was killed previously by a WW. In this case, TRC is set to the radar's maximum acquisition time. Discrete event 15 is scheduled at the end of the tracking and acquisition time which will make the initial calculations of the weapon P_k.

Radar-Attack Profile--continued

Subroutine SEARCH returns to event 14 where the network is entered. From event 14 the aircraft takes one of three paths. If the aircraft reached the target area then it will go to node TGT. If the aircraft was killed by a threat weapon system in discrete event 17, which will be described later in the chapter, then the aircraft will take the path to node AKL. If the above two conditions

are not met, then the aircraft will proceed back to node RATK after a one-second activity duration. Thus radars will discretely search for the aircraft as they fly through the threat system in one-second intervals. If the aircraft either reaches the target area or is killed then the screening process stops for that aircraft.

Discrete events 15, 16, 17, 18, and 19 apply to the radar-attack portion of the system. These events are FORTRAN code using SLAM subroutines that evaluate the radar's attack profile on the engaged aircraft.

Event 15, which is scheduled from subroutine SEARCH, occurs at the end of the tracking and acquisition time, TRC. Here, the radar first determines if it has a chance of getting a shot at the aircraft. Subroutine PROB is called which computes the P_k of the weapon, the estimated range to intercept (RI), time of weapons launch (TL), and time of impact (TI). If the P_k is below 5 percent, then the radar is disengaged from the profile and event 19 is scheduled, which releases the radar from the aircraft. Otherwise, the radar-attack profile is continued. If TL is equal to the current simulation time, TNOW, then the threat radar "fires" its associated weapon and event 17 is scheduled to occur at impact time. If TL is greater than TNOW, then event 16 is scheduled at estimated launch time.

Event 16 occurs at launch time, TL. Subroutine PROB passes new estimates of P_k, RI, TL, and TI back to the event. Once again, if the P_k is below 5 percent then event 19 is scheduled to disengage the radar and aircraft. If the P_k is acceptable event 17 is scheduled to occur at the new time of impact.

Event 17 is realized at weapon's impact time. Subroutine PROB is called one last time for the final evaluation of P_k and RI. If the aircraft turned away from the site when the weapon was airborne then RATIO is computed to determine how much its position has changed. If RATIO is greater than 1.1 then event 17 is rescheduled with time of occurrence set how long it takes the weapon to get to the new intercept range. If the aircraft did not turn or did turn but the turn was not appreciable, then a kill determination is made by using a random sample draw. If the aircraft is killed, then XX(54) is set to the call sign of the aircraft to key the network. Global variable XX(59) or XX(57) is incremented as appropriate and all events associated with the destroyed aircraft are removed from the event calendar. In any case, event 18 is scheduled to occur in 30 seconds, representing the delay time of disengaging the radar from the aircraft.

Event 18 frees the appropriate radars to re-engage new targets. If the aircraft was not killed, ATRIB(6) not equal to 1, then only that radar that fired at the

AD-A115 702 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOO--ETC F/G 17/4
A WILD WEASEL PENETRATION MODEL.(U)
MAR 82 K C ANDERSON, R B NENNER
UNCLASSIFIED AFIT/GST/OS/82M-1 NL

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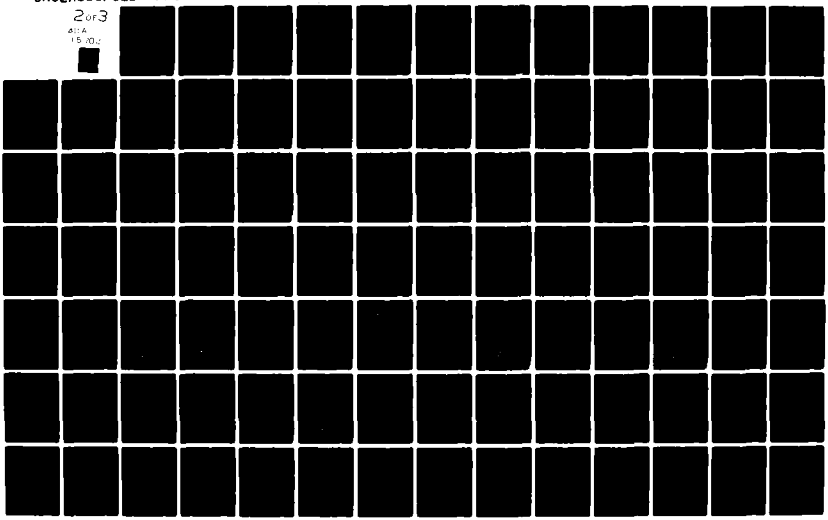


aircraft is released. If the aricraft was killed, then all radars associated with it are disengaged.

Subroutine PROB

This subroutine calculates the probability of kill for the threat weapon system, the range to intercept the target aircraft (RI), the time of weapons launch (TL), and the time of weapons impact (TI). First the attributes of the aircraft are decoded (lines 979-992), the multi-path range calculated, and the appropriate radar-attack file obtained. The distance from radar to aircraft is compared to the multi-path range and the maximum effective weapon range. If the radar-aircraft distance is greater than either of the above then P_k is set to zero and the subroutine terminated.

For the SAM threats the following is accomplished. The relative bearing between the radar and the aircraft is computed (ANG, lines 1014-1025). Based upon whether the aircraft is ahead or behind the threat the appropriate values of TL, TI, and RI are calculated. Aircraft radar cross-section is obtained from File 19 based on the aspect angle between the threat and the aircraft (lines 1056-1061). Next, P_k is calculated. First, if RI is greater than the maximum effective radius of the weapon, P_k is set to zero. Otherwise, CEP is computed based on whether the aircraft

is ECM (attack force) or non-jamming (WW). Using CEP, P_k is calculated.

For the AAA threats the following applies. "G" forces are determined based on whether the aircraft is a WW (turning or straight and level) or an attack force (in or outside the expected area of AAA concentration). P_k calculations are given in lines 1092-1100.

Subroutine INTLC

Subroutine INTLC initializes variables to their starting values. In addition the radar file, File 1, and the WW-attack file, File 2, are built. Radar cross-section data is built and stored in File 19.

Subroutine STATE

Subroutine STATE contains the equations that define the continuous set of variables for the model. These equations explicitly characterize the model as it changes over time. This time-dependent, event-dependent portrayal is fundamental to the concept of the system as a combined simulation model.

Rate equations for the attack force aircraft consist of just one differential equation. Because the attack aircraft never change heading and their heading is 090 degrees in the model's coordinate system, the velocity of the attack aircraft, DD(I), is defined to be a constant, XX(14).

Rate equations for the WW are only slightly more complicated. The WW will have velocity components in both the x and y direction. In addition, because the WW changes heading (direction) as it works its way through the threat environment, its heading rate of change is expressed as a differential equation. Line 39 gives the differential equation for this heading rate change as equal to RATE. The next two equations correct the WW's heading to the limits of 0° to 360°. Lines 45-46 define the velocity of the WW in the x- and y-direction. Next, the WW working designator is evaluated. If the WW is engaged in an attack profile, working designator between one and eight, then the WW does not enter the radar selection phase of STATE (lines 62-75) but instead proceeds to "101" to calculate the remaining STATE variables. If, on the other hand, the working designator is equal to nine, indicating that the WW is out of ARMs, then a designated go home point is chosen (lines 53-57). If the WW's working designator is zero, signifying that the WW is searching for threats to attack, then the radar selection routine is performed (lines 62-75). In this routine the closest radar that the WW can attack from File 2, the WW-attack file, is selected, its sequential number placed in "L" and its coordinates set to XX(I+11) and XX(I+12). Line 76 calculates the distance from the designated radar to the WW. Line 78 is the line-of-sight range to the WW. The relative bearing is

calculated in lines 79-88 based on the position and heading of the WW with respect to the radar. The absolute relative bearing is calculated in lines 89-90 and corrected for the limits of 0° to 180°.

Appendix F lists a summary of the events and subroutines.

In this chapter the structural model was translated into the simulation model using the SLAM language. Basic concepts of simulation modeling were presented and the interfaces of SLAM and the structural model discussed. Once the simulation model has been developed tests are ready to begin. The next chapter demonstrates the capability of the model to analyze WW operations through experimentation.

IV. Experimentation

Overview

The purpose of the research effort was to develop a methodology that could be used to analyze WW defense suppression operations. Once the structural model has been translated into the simulation model then the simulation model can be executed and an experiment conducted to demonstrate the capability of the model to analyze WW operations. In this chapter experimentation of the simulation model is performed. First, the data collection phase is presented: WW variables that may be analyzed in the model are discussed and two are selected for the experiment; experimental design is set forth; sample size for the experiment is determined. In the next phase the experiment is conducted and the results are discussed. In the final phase, the model is validated in a three-step process.

Phase One: Data Collection

The simulation model was constructed with the capability to analyze the WW defense suppression mission firmly in mind. To that end, SLAM global variables were used so that various system variables could be changed quickly and effortlessly to analyze different aspects of the WW mission. Table VI lists these variables and their associated global

TABLE VI

VARIABLES THAT CAN BE CHANGED/EVALUATED

Variable	Global Variable
WW	
Altitude	XX(3)
Velocity	XX(5)
Interval/Spacing	XX(8)
Number in System	XX(6)
ARM Configuration	XX(81-82)
ARM Launch Range	XX(4)
Entry Position	SS(25,29)*
Attack Aircraft	
Altitude	XX(13)
Velocity	XX(14)
Interval/Spacing	XX(7)
Number in System	XX(9)
Entry Position	XX(61-70)
Radar Systems	
Dispersion on LOC	XX(52)

*State Variable--see text.

variable. (The entry positions of WW1 and WW2 are changed with state variables SS(25) and SS(29), respectively.) Through the use of global variables any of the system variables listed in the table can be changed and experiment conducted to analyze their effect on the output data.

To demonstrate the capability of the simulation model two variables were selected for the experiment: WW altitude and WW tactic. These two variables were suggested by WW experts at George AFB (Refs 10; 11) as having significant impact on WW defense suppression operations. The two altitudes chosen for the experiment were 60 meters and 200 meters. At a relatively higher altitude the WW can "see" farther with its radar homing and warning equipment and will be able to begin an attack on threat radars sooner than if it was at a lower altitude. But at the same time, because the WW is at a higher altitude, threat radars will be able to detect the WW sooner and begin their attack on the WW earlier. The two tactics chosen for the experiment were the WW leading the attack force into the threat area by 30 seconds and accompanying the attack force into the threat area. If the WW leads the attack force into the area, it may be possible to attrite enough radars so that more attack aircraft can get to the target area. But the WWs will have increased their exposure time to the threats in this tactic.

In the SLAM program WW altitude is specified at line 172 (XX(3) = 60) and line 178 (XX(3) = 200). Tactic 1, WWs leading the attack force by 30 seconds is specified in the SLAM program in Appendix A. This is denoted by the "30" in the attack aircraft CREATE node entry at line 18 signifying that the time of the first attack aircraft generated in the system is at 30 seconds simulation time. Tactic 2 is not shown in Appendix A but is identical to the Appendix A program except that the attack aircraft CREATE node entry in line 18 is changed from "30" to "5" signifying that the first attack aircraft follows the first WW in the simulation by 5 seconds.

Experimental Design. Experimental design provides a way of deciding which system variables to experiment so that the results can be obtained in the most efficient manner, efficiency equated to least time and money.

(In the terminology of the experimental design the input variables (for the WW model--altitude and tactic) are called factors and the different conditions of the factors (WW altitude of 60 m and 200 m) are called levels.)

The design chosen for the experiment was a full factorial design (Ref 8:372). The full factorial design is one in which all levels of a given factor are combined with all levels of every other factor in the experiment. The advantages of the factorial design are as follows:

1. Maximum efficiency in the estimation of the effects of the variables.

2. Correct identification and interpretation of factor interactions if they exist.

3. The effect of a factor is estimated at several levels of other factors, and thus the conclusions reached hold over a wide range of conditions.

4. Ease of use and interpretation (Ref 14:165).

The main disadvantage of a full factorial experiment is that the number of runs required to test all levels of all factors may become prohibitively excessive. The number of runs required for this experiment did not preclude the use of the full factorial design. This will be discussed in Sample Size Determination.

Measure of Merit. The measure of merit chosen to evaluate the experiment was the number of aircraft surviving each run and reaching the target area. This permitted an analysis of WW defense suppression effectiveness within the context of the model's threat environments.

Sample Size Determination. A simulation model is an abstraction of a real system. Experiments are conducted on the model in order to draw inferences on the real system. Because the model is an abstraction or approximation of the real world, the model must be executed a number of times

before valid inferences can be made on the output data. Determining the number of runs for the experiment is called sample size determination. Determining how large a sample to use in an experiment depends on the size of the risk you're willing to take on the inferences and variability that is present in the model.

The sample size that was chosen for the experiment was determined by Stein's method (Ref 7:482). A trial experiment of five simulations was conducted. Each factor in the trial was set at its lowest level: WW altitude at 60 and WW tactic leading the attack force. The objective of the trial experiment was to be 95 percent confident that the sample mean would be within one aircraft of the true mean. The following equation gives the required number of runs.

$$M = \frac{t_{n-1}^{\alpha/2}}{c} s^2$$

where M = required number of runs,

c = maximum units wrong,

s^2 = sample variance in trial, and

$t_{n-1}^{\alpha/2}$ = t-statistic for $(1-\alpha)$ confidence level with $(n-1)$ degrees of freedom.

The trial experiment produced the following results.

Run	Number of Aircraft Surviving (out of 10)
Run 1	3
Run 2	1
Run 3	1
Run 4	5
Run 5	4

Thus,

$$M = \frac{t_4^{.025}}{c} s^2 = \frac{2.76 \times 3.36}{1} = 9.2$$

The results of the experiment indicated that the minimum number of runs would be 10. This resulted in a total of five replications per cell for the experimental design. See Table VII.

TABLE VII

EXPERIMENTAL DESIGN

	WW ALT--60	WW ALT--200
Tactic 1--WW Leading	xxxxx	xxxxx
Tactic 2--WW Accompanying	xxxxx	xxxxx

x = replication.

Data Analysis

Once the factors and levels for the experiment were chosen, the number of runs determined, and the experimental design set, the experiment was performed. The results of the experiment are analyzed in this phase of the experimentation.

To determine if WW altitude or tactics effected attack force survivability a two-way analysis of variance (ANOVA) statistical procedure was conducted. The output of the statistical analysis along with the results from each experimental run are listed in Appendix G.

The null hypothesis for the experiment is the following.

> H_o: Neither altitude nor tactic effected aircraft survivability.

The test statistic for the experiment is the F-statistic. The null hypothesis is rejected with the F-statistic is greater than the following.

$$F_{.05,1,16} = 4.49$$

The ANOVA shows:

$$F = 1.14$$

Thus the null hypothesis cannot be rejected at the .95 confidence level.

Although the results of the experiment show an inconsequential relationship between the two WW factors and attack force survivability, the experiment must be viewed within the broad perspective of the developed model. The following factors, viewed separately or in combination with one another may have contributed to the experimental results.

1. Threat environment density. The number of threat radars (78) in the threat area was too great for a force of only 2 WW to suppress. The threat radars were not modeled to stop radiating in anticipation of an ARM impact, real or imagined. Whether radars would stop radiating in response to a WW attack in an all-out encounter between NATO and Warsaw Pact is open to conjecture. The simulation model allows for this concept by defining the threat radar's ninth attribute as the radiation attribute. See Appendix E.

2. WW tactic. The WW tactic required the WW to boresight on the threat before an ARM could be launched. In addition, the WW attacked every threat regardless of the attack positioned the WW.

3. Ranging routine. Threats were required to be accurately located before an ARM was launched. This meant that the WW had to complete the entire ranging routine before ARM launch. Another tactic that a WW might use in a radar-rich threat environment is to pre-emptively launch ARMs in anticipation of threat radar emissions. Although

this would decrease the WW's exposure time in the threat area it is not certain to what extent, if any, it would decrease the WW's effectiveness.

4. Self-protection jamming. The WW did not use self-protection jamming either before or after attack by a threat radar. If the WW did use jamming its survivability might be increased.

Needless to say there are many factors that influence and are critical to WW defense suppression operations. A thorough and comprehensive investigation of these many factors is easily realized with this WW simulation model. Manipulations of various parameters such as altitude, airspeed, timing tactics, radar shutdown, and jamming can be accomplished with minor adjustments of the defining simulation variables.

Validation

Law and Kelton (Ref 8:338) elaborate on a three-step approach to validation that was first presented by Naylor and Finger.

1. Develop the model with high face validity.
2. Test assumptions of the model empirically.
3. Determine how representative the simulation data are.

This three-step approach will be used for the WW simulation model in order to establish its validity.

Model Face Validity. A model that has high face validity is one which seems reasonable to people who are knowledgeable about the system. To establish the model's face validity the following was accomplished.

1. Before the WW model was developed, experts on WW employment from the 37th Tactical Fighter Wing at George AFB were interviewed. Crew members and instructors who are familiar with the WW and its varying missions were consulted. In addition, as the model was being built, these experts were asked to confirm various aspects on possible WW tactics and current operational concepts to make sure that the model's assumptions were realistic (Ref 11).

2. In order that the model's threat environment be represetnative of a typical enemy threat array, defensive systems experts were consulted (Ref 4). The threat scenario that resulted developed from these consultations.

Empirical Tests. In order to ensure that the model behaved as it was intended to behave, quantitative tests were run. These tests consisted of the following.

1. WW Profile. To determine the validity of the WW attack portion of the model, a WW was followed as it proceeded through the threat array hunting for radars to attack. The logic and action points, as well as the probability of kill routine for the WW, were hand-calculated and then compared to model output. The results are listed

in Appendix I. The model's output compares favorably with the hand-calculated figures.

2. Radar-Attack Profile. As with the WW portion of the model, the logic and subroutines of the radar-attack profile are validated by following an attack force aircraft as it flies through the threat array. The results are listed in Appendix I and these too compare favorably.

3. Extreme Values. The model was tested at extreme values of various system parameters to determine if the model behaved as it should. When attack aircraft velocity was decreased to 50 m/sec, all aircraft were killed. Similarly, when attack aircraft altitude was set at zero, all but one aircraft survived, the lone kill being recorded by AAA. Additionally, WW altitude was decreased to zero and WWs were able to launch a total of seven ARMs before being killed by AAA.

<u>Simulation Output Data</u>. The best test for a simulation model would be to establish that the model's output data closely follows the output data one would expect from the real system being modeled. Because the developed WW simulation model had no equivalent system with which to test it, a modified Turing test (Ref 8:341) was conducted. The object of the Turing test was to compare the model's output data against a hypothetical system by experts who are knowledgeable with the system. To that end three WW

experts were asked to predict the outcome of the model's threat scenario given the same input data as the model's. The WW experts consisted of two crew members and a WW systems project officer, all of whom are familiar with the capabilities and concept of operation of the F-4G WW. The predictions of the panel of experts agreed consistently with the model output data.

In this chapter experimentation of the simulation model was presented. This included selecting the data and methodology for the experiment, performing the experiment, and analyzing the results. In addition, the three-step process of model validation was discussed. In the next chapter, conclusions and recommendations are presented.

V. Conclusions and Recommendations

The objective of this thesis, as stated in Chapter I, was to develop a methodology, through a simulation model, for evaluating the WW defense suppression mission. Conclusions resulting from this objective break down into two categories:

1. Primary--those based on the SLAM modeling of the FEBA air battle, and

2. Secondary--those based on the model's experimental results.

Primary Conclusions

This thesis developed a model for evaluating combined air operations and tactics near the FEBA. The model expanded on Leek and Schmidt's initial work by including WW defense suppression support for an ingressing fighter strike force. The model required the flexibility to allow an experimenter the latitude for evaluating alternative procedures and tactics yet retain the accuracy required to portray the actual combat area. The SLAM model does capture the dynamic nature of the FEBA air battle. The combined modeling approach allows the experimenter to view the interactions between the aircraft and threats on a moment-by-moment basis. SLAM's flexibility offers an experimenter

the opportunity of varying the state and global variables to design meaningful experiments and evaluate effects on WW tactics and procedures. Appendix C lists these variables and gives an idea to the type of experimental design that can be undertaken.

Experiment Conclusions

The model's present structure was developed with the objective of obtaining the highest P_k per engagement for both the WW and enemy threat systems independent of other action. It represents the most restrictive case for both the major system elements (WWs and threats) and required the most computer logic and subroutines. At the other end of the scenario spectrum lies the area of maximum self-protection for both elements. It requires little logic (stay low for the WW and do not radiate for the threat radars). In between these two extremes lies the area of actual operations and an area where experimentation can be done: achieve a desired level of P_k on a threat while achieving some desired level of self-protection.

Consider the WW. Its stated objective for a defense suppression mission is to eliminate the enemy's radar controlled weapon threat. The existing model simulates a methodology which attempts to maximize this probability of destroying the threat. The WW's ranging routine duration (30 degree of relative bearing change) represents

the method of most accurately determining the threat's location given the WW must operate in the low altitude arena. The attack phase requirement for boresighting on the threat again represents the method required for achieving the highest P_k.

The same can be said of the threat's portion of the model. The logic attempted to maximize the single engagement P_k. For both the SAM and AAA systems, the shot was delayed, if possible, until the aircraft came abeam the site, thus increasing the maximum radar cross-section while launching at the minimum range (resulting in the minimum CEP and maximum P_k).

To get from the restrictive case of the existing model to a likely operational area requires small deletions from and changes to the existing model whereas going from the total self-protection end of the spectrum to the operational area requires major additions to the program. For this reason the restrictive case is easier for an experimenter to use and modify. The experimental conclusions and recommendations are made with this in mind and represent areas where operators in the field indicate a need exists for additional study and the analyst can readily adapt the model.

The model's experiment of varying WW tactics (timing with the strike force) and altitude did not affect strike force survivability. It must be emphasized that this

conclusion is drawn based on the constraints and limitations imposed in the model. In addition, the experiment's measure of merit was strike force aircraft reaching the target and not WW survivability. The results appear consistent for an area where the ground threats enjoy a 7:1 numerical advantage over the aircraft.

Specific limitations and constraints imposed by the model on the WW and affecting its performance are explained below. In general, the WW tactics employed in the model increased the WW exposure time in the threat environment.

1. The WW continued to attack threats until it depleted all weapons. In the dense threat environment this longer exposure time to the threats increased the site's P_k against the WW. (Restrictive case discussed above.)

2. The WW did not employ an ARM turn launch option (off the boresight axis). The increased time required to turn and boresight on the threat again increased the WW's exposure time. (Again, restrictive case discussed above.)

3. The WW did not immediately abort the mission scenario if the slant range to the site was less than the minimum ARM range. (Restrictive case.)

4. The WW ARM's P_k against a site did not vary for launch altitude, although degradation for lower launch

altitude does exist. (Restrictive case.)

Model limitations imposed on the threat radars and affecting the experiment's outcome are listed below:

1. The SAMs did not have a minimum launch range. Actual SAMs have both a minimum and maximum launch range. By excluding the minimum range, the site could allow the aircraft to fly over the site before launching a missile and thus the model calculated an inflated P_k based on this lower launch range to impact.

2. The sites neither jammed the WW's RHAW receivers nor stopped radiating if detecting a possible WW attack.

3. The threat radars were modeled as totally concentrating on the attacking aircraft. Combined arms operations near the FEBA may hinder the site's operation when other ground threats in the area attack near the SAM sites.

4. The threat network included neither infrared (IR) and visual detection means nor small arms fire.

Recommendations

Based on the experimental conclusions, the following recommendations are made (here, the model moves from the restrictive to operational):

1. When possible, ARM launch should occur at the maximum launch range.

2. If the WW finds itself in a position inside the minimum launch range, the aircraft should immediately

abort the attack and not attempt to maneuver to achieve a permissible launch condition.

3. An effort should be made to decrease the time required to complete the ranging phase of the mission.

4. WW crews should always operate at the lowest possible altitude.

5. An analysis should be continued in developing a longer range ARM.

VI. Recommended Follow-on Study

This thesis concentrated on developing a model for experimenting with combined air operations near the FEBA and did not concentrate on the actual experimentation. The model achieved an operational status and is now ready to be used for experimentation. The following indicate possible follow-on study areas:

1. The WW preemptive ARM launch option should be investigated. Preemptive launch requires no mission ranging phase. Based on intelligence estimates the crew launches its ARM into a concentrated area of weapons from a maximum range.

2. The use of WW self-protective ECM and its effect on WW survivability must be analyzed. This may be limited by the WW's onboard RHAW equipment and the possible interference.

3. The number of ARM launches the WW attempts per mission may affect its survivability. For example, continuous attacks in a dense threat radar environment resulted in the WW being destroyed on all experiment runs. By limiting the attacks to a smaller number per mission, followed by the WW withdrawing to safe airspace may increase the number of surviving WW.

4. A modification of the model would allow the WW to employ the ARM launches from its turn mode, thus decreasing the time required to perform each mission scenario.

Bibliography

1. AFM 1-1. United States Air Force Basic Doctrine. Washington: Department of the Air Force (February 1979).

2. AFM 11-1, Vol. I. United States Air Force Glossary of Standard Terms. Washington: Department of the Air Force (January 1973).

3. Breuer, Walter. Lecture material for SE 5.80, Analytical Aspects of Weapons Delivery. School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 1980.

4. Campinile, Frank and John Kordik. Mission Analysis Branch, Aeronautical Systems Division (personal interviews). Wright-Patterson AFB, Ohio, 15 September 1981 to 12 February 1982.

5. Golden, Major August. Lecture material for EE 5.73, Electronic Warfare. School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 10 December 1981.

6. Gray, Colin. "Soviet Tactical Airpower," Air Force Magazine, No. 38: 68-72 (March 1977).

7. Kleijnen, Jack P. C. Statistical Techniques in Simulation, Part II. New York: Marcel Dekker, 1975.

8. Law, Averill M. and W. David Kelton. Simulation Modeling and Analysis. New York: McGraw-Hill Book Company, 1982.

9. Leek, Warren J. and Richard W. Schmitt. "Survivability Study of a FLIR Equipped Fighter on a Night Penetration of a Soviet Army." Master of Science Thesis. School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, March 1981.

10. Noel, Lt Col Martin F. Operations Officer, 562 Tactical Fighter Training Squadron (personal interview). George AFB, California, 29-31 September 1981.

11. Peacock, Lt Col Samuel. Academic Branch Chief, 563 Tactical Fighter Training Squadron (telephone conversations). George AFB, California, 15 November 1981 to 12 February 1982.

12. Pritsker, A. Alan B. and Claude Dennis Pegden. Introduction to Simulation and SLAM. New York: John Wiley and Sons, 1979.

13. Severson, J. and T. McMurchie. "Antiaircraft Artillery Simulation Computer Program--AFATL Program P-001," JTCG Technical Note 4565-16-73.

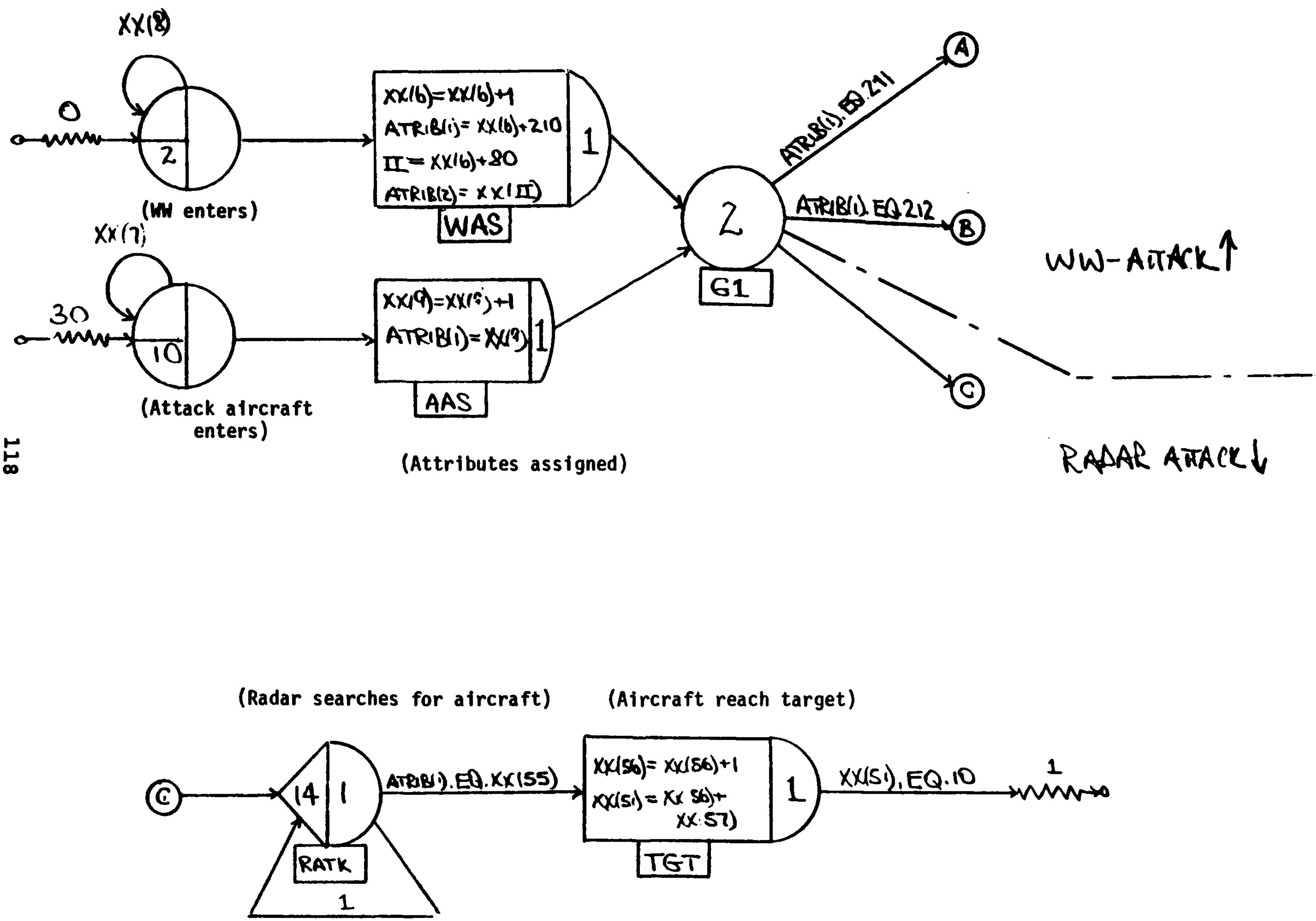
14. Shannon, Robert E. Systems Simulation--The Art and Science. Englewood Cliffs, New Jersey: Prentice Hall, Inc., 1975.

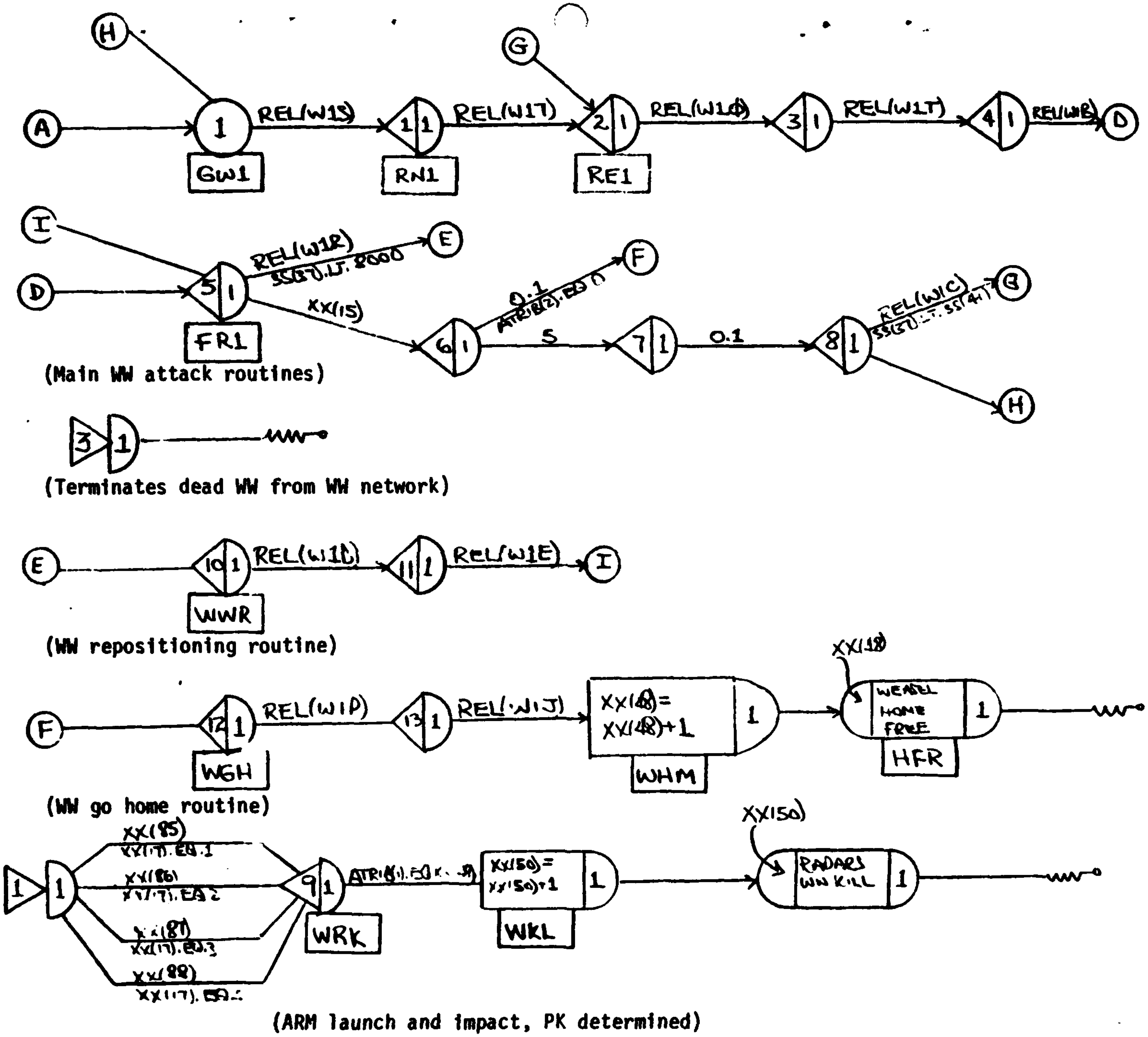
15. Skolnik, Merrill I. Introduction to Radar Systems. 2d ed. New York: McGraw Hill, 1981.

16. (author unknown). Considerations for Tactics Development (unpublished pamphlet), 563 Tactical Fighter Training Squadron, George AFB, California, 1981.

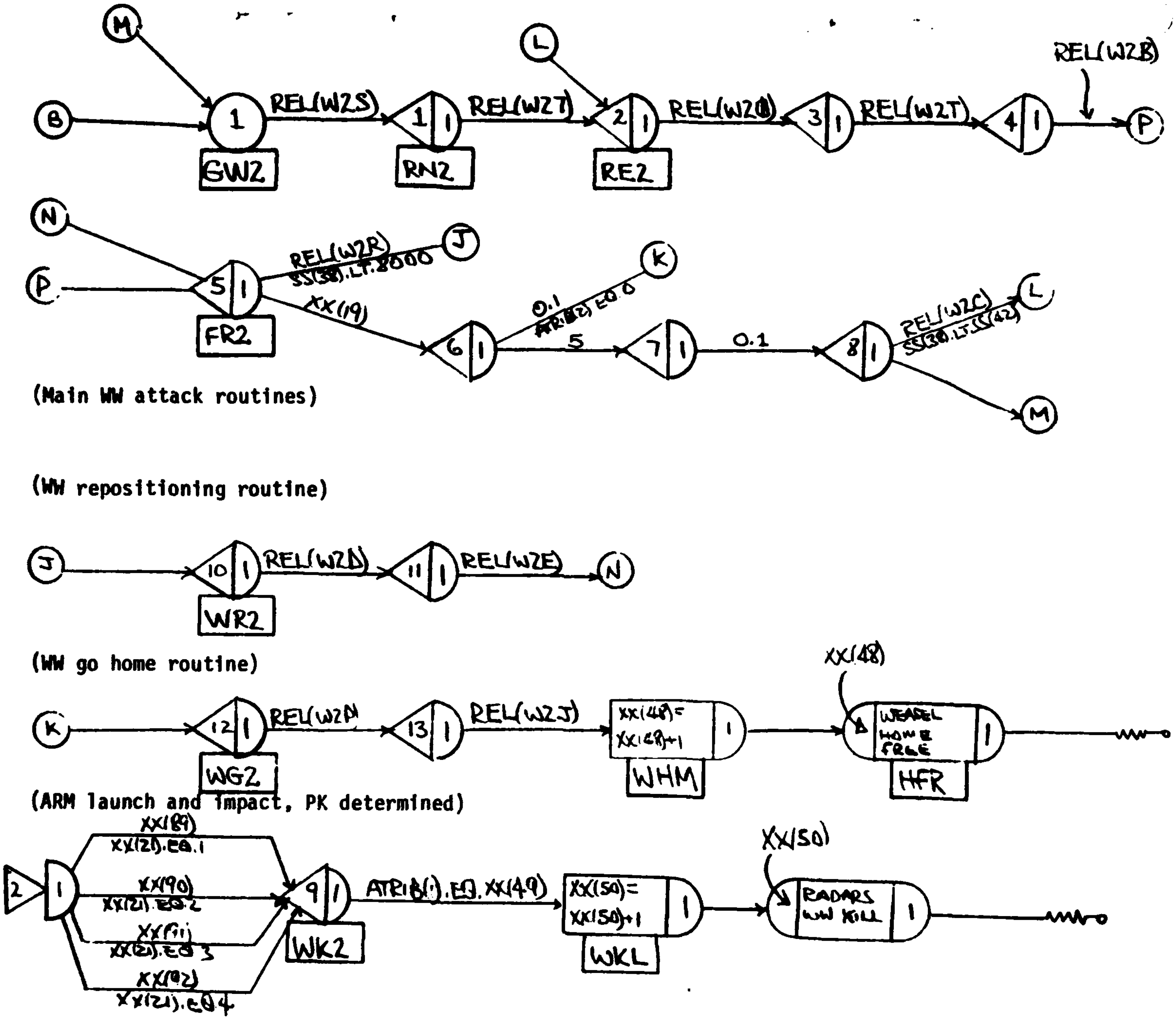
Appendix A

SLAM Network

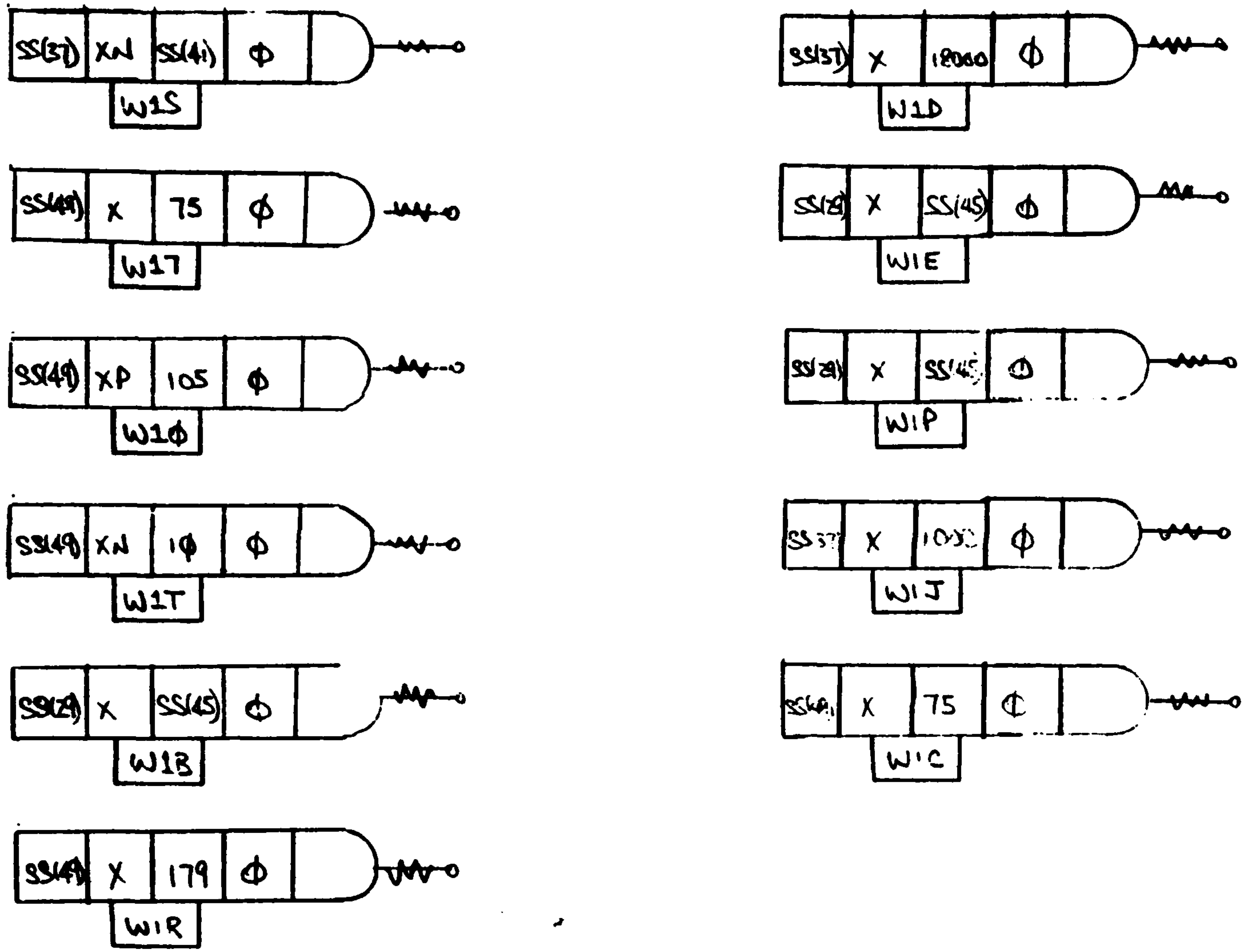

XX(8)
0
2
(WW enters)
XX(7)
30
10
(Attack aircraft enters)
XX(6)=XX(6)+1
ATRIB(1)= XX(6)+210
II = XX(6)+80
ATRIB(2)= XX(II)
1
WAS
XX(9)=XX(9)+1
ATRIB(1)=XX(9)
1
AAS
(Attributes assigned)
2
G1
ATRIB(1).EQ.211
ATRIB(1).EQ.212
A
B
C
WW-ATTACK↑
RADAR ATTACK↓
(Radar searches for aircraft)
(Aircraft reach target)
C
14
1
RATK
1
ATRIB(1).EQ.XX(55)
XX(56)= XX(56)+1
XX(51) = XX(56)+ XX(57)
1
TGT
XX(51).EQ.10
1



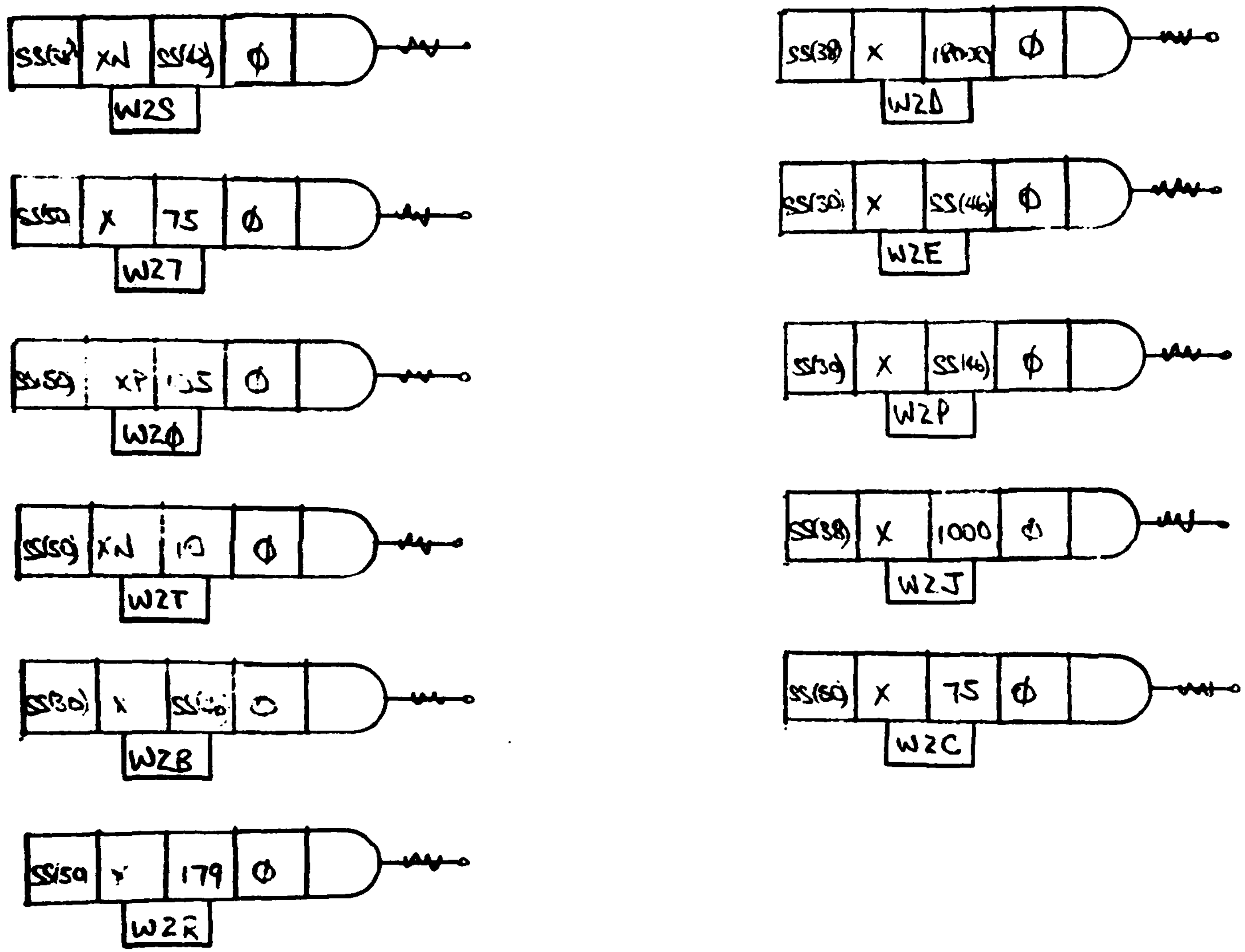
WILD WEASEL 1 - ATTACK PROFILE NETWORK



WILD WEASEL 2 - ATTACK PROFILE NETWORK



WILD WEASEL 1 - DETECT NODES



WILD WEASEL 2 - DETECT NODES

Appendix B

SLAM State Variables

SS	Use	Corresponding DD	Definition of DD
1-10	Attack aircraft (1-10) x-position	1-10	Velocity
21	WW1 x-position	21	WW1 velocity in x-direction
22	WW2 x-position	22	WW2 velocity in x-direction
25	WW1 y-position	25	WW1 velocity in y-direction
26	WW2 y-position	26	WW2 velocity in y-direction
29	WW1 heading	29	WW1 heading rate change
30	WW2 heading	30	WW2 heading rate change
33	WW1 working designator	—	
34	WW2 working designator	—	
37	Distance from WW1 to attacked threat	—	
38	Distance from WW2 to attacked threat	—	
41	WW1 line-of-sight distance	—	
42	WW2 line-of-sight distance	—	
45	WW1 relative bearing to threat	—	
46	WW2 relative bearing to threat	—	
49	WW1 absolute relative bearing to threat	—	
50	WW2 absolute relative bearing to threat	—	

Appendix C

SLAM Global Variables

XX	Use
1-2	Not used
3	WW altitude
4	Actual firing range of ARM
5	WW velocity
6	Counter for number of WWs created
7	Time between creations for attack force aircraft
8	Time between creations for WW
9	Counter for number of attack aircraft created
11-12	Not used
13	Attack force altitude
14	Attack force velocity
15	Time for WW1 to get to ARM release point after completion of triangulation route
16	ARM time of flight for WW1
17	ARM counter for WW1 (number of ARMs launched)
18	Not used
19	Time for WW2 to get to ARM release point
20	ARM time of flight for WW2
21	ARM counter for WW2
22-31	Not used
32	x-position of threat being attacked by WW1
33	x-position of threat being attacked by WW2
34-35	Not used
36	y-position of threat being attacked by WW1
37	y-position of threat being attacked by WW2
38-47	Not used
48	Counter for WWs reaching "home"
49	Flag for threat killed by a WW
50	Counter for threats killed by a WW
51	Not used
52	Standard deviation for road network

XX	Use
53	Not used
54	Flag for WW1 killed by a threat
55	Flag for attack aircraft reaching target
56	Counter for attack aircraft reaching target
57	Counter for attack aircraft killed by threats
58	Flag for WW2 killed by threat
59	Counter for WWs killed by aircraft
60	Not used
61-70	y-position of attack aircraft 1-10
81	ARM load of WW1
82	ARM load of WW2
83-84	Not used
85	Flight time ARM #1 WW1
86	Flight time ARM #2 WW1
87	Flight time ARM #3 WW1
88	Flight time ARM #4 WW1
89-92	Flight time ARM #1 through #4 for WW2

Appendix D

SLAM File Structure

File	Use
1	All radars in threat scenario
2	Radars that WWs can attack
3	WW1 working threat file
4	WW1 kill file--radars that WW1 has killed
5	WW2 working threat file
6	WW2 kill file--radars that WW2 has killed
7-16	Radar aircraft files; file 7 contains those radars engaged with aircraft 1, file 8 with aircraft 2, etc.
17	Radar--WW1 file
18	Radar--WW2 file
19	Data for radar cross-section

Appendix E

Attribute Listing

Aircraft Entity

Attribute	Use
1	Call sign
	WW—211, 212
	Attack—1 to 10
2	ARM Load (WW only)

Radar Entity

Attribute	Use
1	Sequential number (1-85)
2	Type
	1—AAA
	2—SAM-A
	3—SAM-B
	4—SAM-C
	5—SAM-D
	6—EW
3	x-position
4	y-position
5	Associated EW
	0—None
	10—Associated EW killed by WW
6	Threat maximum effect range (meters)
7	Threat minimum effective altitude (m)
8	Call sign of aircraft being attacked by threat
9	Radiating
	0—No
	1—Yes
14	Call sign of WW attacking threat

Appendix F

Subroutine and Event Summary

Event/ Subroutine	Type	Function and Comments
1	WW only	Starts WW ranging routine; realized from DETECT nodes W1S or W2S
2	WW only	Rolls WW out of turn; realized from DETECT nodes W17 or W27
3	WW only	Starts WW back into threat it is attacking; realized from DETECT nodes W10 or W20
4	WW only	Reduces WW heading rate as it starts to line up for ARM launch; realized from DETECT nodes W1T or W2T
5	WW only	Determines ARM firing parameters or if too close to threat starts repositioning routine; event realized from DETECT nodes W1B or W2B
6	WW only	ARM fired at this event; ENTER nodes 1 or 2 are called to determine ARM PK; event realized at the end of ARM release time--XX(15/19)
7	WW only	Gets the WW back into the hunting stage 5 seconds after ARM release
8	WW only	Enters WW back into network based on position and threat it's to attack
9	WW only	Realized from WW ENTER node 1/2; determines PK of the ARM; removes radar from appropriate file (as necessary)
10	WW only	Repositioning routine event; realized from event 5 after time duration of DETECT node W1R or W2R

Event/ Subroutine	Type	Function and Comments
11	WW only	Repositioning routine; realized from DETECT node W1D or W2D
12	WW only	Starts WW home after it fires its last ARM; previous event—event 6 (ARM launch event)
13	WW only	Rolls WW out after its initial turn home; from DETECT node W1P or W2P
14	All acft	Radar search event; occurs every 1 second as long as the aircraft is in the FEBA area and not killed; calls subroutine SEARCH; evaluates if aircraft has reached target area; allows only a maximum of 5 threats to work aircraft; this is a network event
15	All acft	Discrete event; called at the end of tracking and acquisition time by function SCHDL in subroutine SEARCH; based on evaluation of PK for the threat, events 16, 17, or 19 are scheduled
16	All acft	Discrete event; called at time of launch (TL) from event 15 by SCHDL function; based on PK, event 17 or 19 is scheduled
17	All acft	Discrete event; call at time of weapons impact (TI) from event 15 ot 16 by SCHDL function; event 18 is scheduled 30 seconds from this event's time

Event/ Subroutine	Type	Function and Comments
18	All acft	Discrete event; called from event 17; releases appropriate radars if aircraft was killed/not killed, removes aircraft from network if killed
19	All acft	Discrete event; called from event 15 or 16 when PK is below certain value; frees radars to search for new aircraft to attack
SEARCH	All acft	Discrete event; called by event 14; radars are paired up with aircraft based on correct values of radar/aircraft; event 15 is scheduled based on calculation of tracking and acquisition time for radar
PROB	All acft	Discrete event; called from event 15, 16, and/or 17; evaluates four factors--time of launch (TL), time of impact (TI), range to intercept (RI), and PK of weapon (PKR)

Appendix G

SLAM Computer Model

```
  RBN,CM170000,T1000,IO100. T820024,NENNER,4567
ATTACH,PROCFIL,ID=A810171,SN=ASDAD.
BEGIN,NOSFILE.
GET,BBWE,ID=MAGGIE.
ATTACH,PROCFIL,SLAMPROC,ID=AFIT.
BEGIN,SLAM,,M=BBWE,PL=16000.
GEN,ANDERSON AND NENNER,THESIS,2/9/82,10,YES;
LIMITS,19,14,500;
INITIALIZE,0,800;
CONTINUOUS,32,20,1,5,10;
NETWORK;
      CREATE,XX(8),0,,2,1;
      ACT/1;
;WEASEL ASSIGN NODE
WAS   ASSIGN,XX(6)=XX(6)+1,ATRIB(1)=XX(6)+210;
      ASSIGN,II=XX(6)+80,ATRIB(2)=XX(II);
      ACT/2,,,G1;
      CREATE,XX(7),30,,10,1;
      ACT/3;
;ATTACK FORCE ASSIGN NODE
AAS   ASSIGN,XX(9)=XX(9)+1,ATRIB(1)=XX(9);
      ACT/4;
G1    GOON,2;
      ACT,,ATRIB(1).EQ.211,GW1;
      ACT,,ATRIB(1).EQ.212,GW2;
      ACT,,,RATK;
;NETWORK FOR WW1
GW1   GOON,1;
      ACT,,SS(37).LT.SS(41),RN1;
      ACT,REL(W1S);
RN1   EVENT,1,1;
      ACT,REL(W17);
RE1   EVENT,2,1;
      ACT,REL(W10);
      EVENT,3,1;
      ACT,REL(W1T);
      EVENT,4,1;
      ACT,REL(W1B);
FR1   EVENT,5,1;
      ACT,REL(W1R),SS(37).LT.8000.0,WWR;
      ACT,XX(15);
      EVENT,6,1;
      ACT,.1,ATRIB(2).EQ.0,WCH;
      ACT,5;
      EVENT,7,1;
      ACT,.1;
      EVENT,8,1;
      ACT,REL(W1C),SS(37).LT.SS(41),RE1;
      ACT,,,GW1;
      ENTER,1,1;
```

```
        ACT,XX(85),XX(17).EQ.1,WRK;
        ACT,XX(86),XX(17).EQ.2,WRK;
        ACT,XX(87),XX(17).EQ.3,WRK;
        ACT,XX(88),XX(17).EQ.4,WRK;
WRK     EVENT,9,1;
        ACT,,ATRIB(1).EQ.XX(49);
WKL     ASSIGN,XX(50)=XX(50)+1;
        ACT;
        COLCT,XX(50),RADARS WW KILL;
        ACT;
        TERM;
WWR     EVENT,10,1;
        ACT,REL(W1D);
        EVENT,11,1,;
        ACT,REL(W1E),,FR1;
WGH     EVENT,12,1;
        ACT,REL(W1P);
        EVENT,13,1;
        ACT,REL(W1J);
WHM     ASSIGN,XX(48)=XX(48)+1;
        ACT;
HFR     COLCT,XX(48),WEASEL HOME FREE;
        ACT;
        TERM;
;NETWORK FOR WW2
GW2     GOON,1;
        ACT,,SS(38).LT.SS(42),RN2;
        ACT,REL(W2S);
RN2     EVENT,1,1;
        ACT,REL(W27);
RE2     EVENT,2,1;
        ACT,REL(W20);
        EVENT,3,1;
        ACT,REL(W2T);
        EVENT,4,1;
        ACT,REL(W2B);
FR2     EVENT,5,1;
        ACT,REL(W2R),SS(38).LT.8000.0,WR2;
        ACT,XX(19);
        EVENT,6,1;
        ACT,,ATRIB(2).EQ.0,WC2;
        ACT,5;
        EVENT,7,1;
        ACT,.1;
        EVENT,8,1;
        ACT,REL(W2C),SS(38).LT.SS(42),RE2;
        ACT,,,GW2;
WR2     EVENT,10,1;
        ACT,REL(W2D);
        EVENT,11,1;
```

```
          ACT,REL(W2E),,FR2;
     WC2  EVENT,12,1;
          ACT,REL(W2P);
          EVENT,13,1;
          ACT,REL(W2J),,WHM;
          ENTER,2,1;
          ACT,XX(89),XX(21).EQ.1,WK2;
          ACT,XX(90),XX(21).EQ.2,WK2;
          ACT,XX(91),XX(21).EQ.3,WK2;
          ACT,XX(92),XX(21).EQ.4,WK2;
     WK2  EVENT,9,1;
          ACT,,ATRIB(1).EQ.XX(49),WKL;
          ENTER,3,1;
          TERM;
     ;DETECT NODES FOR WW'S
     ;DETECT FOR WW1
     W1S  DETECT,SS(37),XN,SS(41);
          TERM;
     W17  DETECT,SS(49),X,75.0,0;
          TERM;
     W10  DETECT,SS(49),XP,105,0;
          TERM;
     W1T  DETECT,SS(49),XN,10,0;
          TERM;
     W1B  DETECT,SS(29),X,SS(45),0;
          TERM;
     W1R  DETECT,SS(49),X,179,0;
          TERM;
     W1D  DETECT,SS(37),X,10000,0;
          TERM;
     W1E  DETECT,SS(29),X,SS(45),0;
          TERM;
     W1P  DETECT,SS(29),X,SS(45),0;
          TERM;
     W1J  DETECT,SS(37),X,1000,0;
          TERM;
     W1C  DETECT,SS(49),X,75,0;
          TERM;
     ;DETECT NODES FOR WW2
     W2S  DETECT,SS(38),XN,SS(42),0;
          TERM;
     W27  DETECT,SS(50),X,75,0;
          TERM;
     W20  DETECT,SS(50),XP,105,0;
          TERM;
     W2T  DETECT,SS(50),XN,10,0;
          TERM;
     W2B  DETECT,SS(30),X,SS(46),0;
          TERM;
     W2R  DETECT,SS(50),X,179,0;
```

```
          TERM;
W2D       DETECT,SS(38),X,18000,0;
          TERM;
W2E       DETECT,SS(30),X,SS(46),0;
          TERM;
W2P       DETECT,SS(30),X,SS(46),0;
          TERM;
W2J       DETECT,SS(38),X,1000,0;
          TERM;
W2C       DETECT,SS(50),X,75,0;
          TERM;
;
;NETWORK FOR ALL AIRCRAFT
;
RATK      EVENT,14,1;
          ACT,,ATRIB(1).EQ.XX(55),TGT;
          ACT,1,,RATK;
TGT       ASSIGN,XX(56)=XX(56)+1,XX(51)=XX(56)+XX(57);
          ACT,,XX(51).EQ.10;
          TERM,1;
          ENDNETWORK;
INTLC,XX(7)=5,XX(8)=30,XX(3)=60;
SIMULATE;
SIMULATE;
SIMULATE;
SIMULATE;
SIMULATE;
INTLC,XX(3)=200;
SIMULATE;
SIMULATE;
SIMULATE;
SIMULATE;
SIMULATE;
FIN;
```

```
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)
      DIMENSION NSET(25000)
      COMMON QSET(25000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLN
     &,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
     &TNOW,XX(100)
      EQUIVALENCE(NSET(1),QSET(1))
      NCRDR=5
      NPRNT=6
      NTAPE=7
      NNSET=25000
      CALL SLAM
      STOP
      END
      SUBROUTINE STATE
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLN
     &,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
     &TNOW,XX(100)
      COMMON/UCOM1/RATE(2),L(2)
      DIMENSION A(16)
C
C       RATE EQUATIONS FOR STRIKE AIRCRAFT
C
      JJ=XX(9)
      IF(JJ.EQ.0)GO TO 15
      DO 10 I=1,JJ
      DD(I)=XX(14)
10    CONTINUE
C
C       RATE EQUATIONS FOR WW AIRCRAFT
C
15    KK=XX(6)+20
      IF(KK.EQ.20)RETURN
      DO 20 I=21,KK
      J=I-20
C
C        HEADING RATE CHANGE IS EQUAL TO RATE
C
      DD(I+8)=RATE(J)
      IF(SS(I+8).LT.0)SS(I+8)=SS(I+8)+360
      IF(SS(I+8).GT.360)SS(I+8)=SS(I+8)-360
C
C        VELOCITY OF WW IN X-DIRECTION AND Y-DIRECTION
C
      DD(I)=XX(5)*COSD(90-SS(I+8))
      DD(I+4)=XX(5)*SIND(90-SS(I+8))
C
C        BASED ON THE VALUE OF THE WW WORKING DESIGNATOR,
C        EITHER COMPUTE A "LOOK AHEAD" RADAR TO ATTACK
C        OR PROCEED WITH OTHER STATE VARIABLE COMPUTATIONS.
```

```
      C
          IF(SS(I+12).GT.0.AND.SS(I+12).LT.9)GO TO 101
          IF(SS(I+12).EQ.9)THEN
            XX(I+11)=0.0
            XX(I+15)=-10000.0
            GO TO 101
          ENDIF
      C
      C     PRE-SELECT RADAR FOR WW TO ATTACK BASED ON THE
      C     CLOSEST RADAR TO THE WW.
      C
          SR2=999999999.9
          DO 22 IQ=1,NNQ(2)
            CALL COPY(IQ,2,A)
            IF(A(14).GT.0)GO TO 22
            X=A(3)
            Y=A(4)
            SR1=SQRT((SS(I)-X)**2+(SS(I+4)-Y)**2+XX(3)**2)
            IF(SR1.LT.SR2)THEN
              SR2=SR1
              L(J)=A(1)
              XX(I+11)=X
              XX(I+15)=Y
            ENDIF
      22  CONTINUE
      101 SS(I+16)=SQRT((SS(I)-XX(I+11))**2+(SS(I+4)-XX(I+15))
         &**2+XX(3)**2)
          SS(I+20)=4117.2*SQRT(XX(3))
          D=(XX(I+15)-SS(I+4))/(XX(I+11)-SS(I))
          IF(D.GE.0.AND.(XX(I+15)-SS(I+4)).GE.0)THEN
           SS(I+24)=57.3*ATAN(1/D)
          ELSEIF(D.LT.0.AND.(XX(I+15)-SS(I+4)).GE.0)THEN
           SS(I+24)=270+57.3*ABS(ATAN(D))
          ELSEIF(D.LT.0.AND.(XX(I+15)-SS(I+4)).LT.0)THEN
           SS(I+24)=90+57.3*ABS(ATAN(D))
          ELSE
           SS(I+24)=270-57.3*ATAN(D)
          ENDIF
          SS(I+28)=ABS(SS(I+8)-SS(I+24))
          IF(SS(I+28).GT.180)SS(I+28)=360-SS(I+28)
      20  CONTINUE
          RETURN
          END
```

```
      SUBROUTINE INTLC()
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLN
     &NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
     &TNOW,XX(100)
      DIMENSION RNC(12),A(16),ARY(37,6)
      COMMON/UCOM1/RATE(2),L(2)
      DATA A/16*0.0/
      DATA RNC/12*30000.0/
C
C        DATA IN "ARY" IS USED TO CALCULATE THE RADAR CROSS
C        SECTION OF THE AIRCRAFT BASED ON THE ASPECT THE RADAR
C        VIEWS THE AIRCRAFT.  "ARY" IS PLACED IN FILE 19.
C
      DATA((ARY(IA,JA),JA=1,6),IA=1,37)/0,-21.8,-19.3,-26.4,-26.4,-21.
     &5,-23.3,-25.3,-29.6,-29.6,-23.3,10,-28.1,-25.4,-27.5,-27.5,-28.1
     &15,-26.5,-32.3,-27.,-27.,-26.5,20,-19.2,-25.2,-28.3,-28.3,-19.2,
     &25,-26.1,-27.3,-27.5,-27.5,-26.1,30,-24.8,-28.8,-19.4,-19.4,-25.
     &35,-31.2,-31.7,-22.1,-22.1,-31.2,40,-28.3,-27.9,-26.6,-26.6,-28.
     &45,-23.7,-25.3,-26.3,-26.3,-23.7,50,-27.,-28.3,-31.,-31.,-26.9,
     &55,-29.,-28.9,-30.7,-30.7,-29.,60,-28.1,-34.,-31.,-31.,-28.1,
     &65,-29.8,-29.6,-30.,-30.,-29.8,70,-21.8,-20.8,-21.6,-21.6,-21.8,
     &75,-16.6,-16.3,-15.5,-15.5,-16.6,80,-13.3,-16.,-13.7,-13.7,-13.3
     &85,-13.9,-16.6,-14.0,-14.0,-13.9,90,-5.6,-4.2,-5.,-5.,-5.6,
     &95,-10.8,-5.1,-10.,-10.,-10.8,100,-13.4,-13.,-14.3,-14.3,-13.4,
     &105,-24.2,-23.,-20.8,-20.8,-24.2,110,-20.5,-20.2,-21.3,-21.3,-21
     &115,-23.8,-28.3,-26.4,-26.4,-23.8,120,-22.,-30.8,-27.7,-27.7,-22
     &125,-25.7,-30.2,-27.,-27.,-25.7,130,-26.5,-32.3,-27.,-27.,-26.5,
     &135,-25.7,-29.9,-31.,-31.,-25.7,140,-26.1,-31.3,-32.6,-32.6,-26.
     &145,-24,-31.9,-29.5,-29.5,-24.,150,-24.8,-27.2,-29.5,-29.5,-24.,
     &155,-23.1,-23.5,-29.6,-29.6,-23.1,160,-27.,-30.,-29.4,-29.4,-27.
     &165,-25.3,-29.5,-24.,-24.,-25.3,170,-20.1,-25.9,-23.5,-23.5,-20.
     &175,-16.5,-25.4,-21.,-21.,-16.5,180,-15.,-29.,-21.,-21.,-15./
      DO 47 IN=1,37
      A(1)=ARY(IN,1)
      A(2)=ARY(IN,2)+30.0
      A(3)=ARY(IN,3)+30.0
      A(4)=ARY(IN,4)+30.0
      A(5)=ARY(IN,5)+30.0
      A(6)=ARY(IN,6)+30.0
      CALL FILEM(19,A)
   47 CONTINUE
C
C        INITIAL VALUES FOR ATTACK AIRCRAFT
C
      DO 21 I=61,70
      XX(I)=UNFRM(24500.0,25500.0,1)
      JJ=I-60
      SS(JJ)=0.0
   21 CONTINUE
C
```

```
C        INITIAL VALUES FOR WW
C
      DO 22 I=21,22
      SS(I)=0.0
      SS(I+4)=UNFRM(24500.0,25500.0,1)
      SS(I+8)=90.0
      SS(I+12)=0.0
      SS(I+16)=0.0
      SS(I+20)=0.0
      SS(I+24)=0.0
      SS(I+28)=0.0
      DD(I+4)=0.0
      DD(I+8)=0.0
22    CONTINUE
C
C        SET VALUES FOR OTHER VARIABLES
C
      XX(52)=6000.0
      XX(5)=247.0
      XX(13)=310.0
      XX(14)=247.0
      XX(81)=22.0
      XX(82)=22.0
      XX(83)=22.0
      XX(84)=22.0
      RATE(1)=0.
      RATE(2)=0.
C
C        CONSTRUCTION OF RADARS
C
      DO 55 I=1,85
      A(1)=I
      IF(A(1).GE.49.AND.A(1).LE.51)GO TO 57
      IF(A(1).GE.52.AND.A(1).LE.60)GO TO 58
      IF(A(1).GE.61.AND.A(1).LE.70)GO TO 59
      IF(A(1).GE.71.AND.A(1).LE.77)GO TO 60
      IF(A(1).GE.78)GO TO 62
C
C        TYPE AAA RADARS
C
      A(2)=1.0
      A(6)=2990.0
      A(7)=0.0
      A(9)=1.0
      IF(A(1).LE.12)THEN
        A(3)=400.0
        A(4)=RNORM(RNG(1),XX(52),1)
       ELSEIF(A(1).LE.24)THEN
        A(3)=1500.0
        A(4)=RNORM(RNG(2),XX(52),1)
```

```
          ELSEIF(A(1).LE.36)THEN
          A(3)=2500.0
          A(4)=RNORM(RNG(3),XX(52),1)
         ELSE
          A(3)=3400.0
          A(4)=RNORM(RNG(4),XX(52),1)
        ENDIF
        GO TO 63
C
C          TYPE SAM-A RADARS
C
57      A(2)=2.0
        A(6)=50050.0
        A(7)=91.0
        A(9)=1.0
        IF(A(1).LE.50)THEN
          A(3)=45000.0
          A(4)=RNORM(RNG(10),XX(52),1)
         ELSE
          A(3)=80000.0
          A(4)=RNORM(RNG(12),XX(52),1)
        ENDIF
        GO TO 63
C
C          TYPE SAM-B RADARS
C
58      A(2)=3.0
        A(6)=74150.0
        A(7)=305.0
        A(9)=1.0
        IF(A(1).LE.54)THEN
          A(3)=10000.0
          A(4)=RNORM(RNG(6),XX(52),1)
         ELSE
          A(3)=25000.0
          A(4)=RNORM(RNG(8),XX(52),1)
        ENDIF
        GO TO 63
C
C          TYPE SAM-C RADARS
C
59      A(2)=4.0
        A(6)=22250.0
        A(7)=15.0
        A(9)=1.0
        IF(A(1).LE.65)THEN
          A(3)=2500.0
          A(4)=RNORM(RNG(3),XX(52),1)
         ELSEIF(A(1).LE.68)THEN
          A(3)=5000.0
```

```
            A(4)=RNORM(RNG(5),XX(52),1)
           ELSE
            A(3)=15000.0
            A(4)=RNORM(RNG(7),XX(52),1)
          ENDIF
          GO TO 63
C
C           TYPE SAM-D RADARS
C
 60       A(2)=5.0
          A(6)=10200.0
          A(7)=45.0
          A(9)=1.0
          IF(A(1).LE.72)THEN
            A(3)=2500.0
            A(4)=RNORM(RNG(3),XX(52),1)
           ELSEIF(A(1).LE.75)THEN
            A(3)=35000.0
            A(4)=RNORM(RNG(9),XX(52),1)
           ELSE
            A(3)=60000.0
            A(4)=RNORM(RNG(11),XX(52),1)
          ENDIF
          GO TO 63
C
C           EW/GCI RADARS
C
 62       A(2)=6.0
          A(9)=1.0
          IF(A(1).LE.79)THEN
            A(3)=5000.0
            A(4)=RNORM(RNG(5),XX(52),1)+1000.0
            A(5)=1.0
            IF(A(1).EQ.79)THEN
              A(4)=A(4)-10000.0
              A(5)=2.0
            ENDIF
           ELSEIF(A(1).LE.80)THEN
            A(3)=10000.0
            A(4)=RNORM(RNG(6),XX(52),1)
            A(5)=3.0
           ELSEIF(A(1).LE.82)THEN
            A(3)=25000.0
            A(4)=RNORM(RNG(8),XX(52),1)+1000.0
            A(5)=4.0
            IF(A(1).EQ.82)THEN
              A(4)=A(4)-10000.0
              A(5)=5.0
            ENDIF
           ELSEIF(A(1).LE.84)THEN
```

```
             A(3)=35000.0
            A(4)=RNORM(RNG(8),XX(52),1)+1000.0
            A(5)=6.0
            IF(A(1).EQ.84)THEN
              A(4)=A(4)-10000.0
            A(5)=7.0
            ENDIF
           ELSE
            A(3)=45000.0
            A(4)=RNORM(RNG(10),XX(52),1)
            A(5)=8.0
          ENDIF
          A(3)=A(3)+50000.0
          GO TO 64
   63     A(3)=A(3)+50000.0
          A(5)=0.0
          IF(A(3).LE.55000)THEN
            IF(A(4).GT.RNG(5))THEN
               IF(DRAND(2).GT..5)A(5)=1.0
            ELSEIF(A(4).LE.RNG(5))THEN
               IF(DRAND(2).GT..5)A(5)=2.0
            ENDIF
           ELSEIF(DRAND(2).GT..5)THEN
            A(5)=8.0
          ENDIF
          IF(A(2).EQ.3)THEN
            IF(A(3).EQ.60000.0)THEN
               A(5)=3.0
            ELSEIF(A(4).GT.RNG(8))THEN
               A(5)=4.0
            ELSE
               A(5)=5.0
            ENDIF
          ENDIF
   64     CONTINUE
          CALL FILEM(1,A)
   55     CONTINUE
C
C          WW RADAR FILE "2" - ONLY THOSE RADARS MEETING CERTAIN
C          SPECIFICATIONS ARE PLACED IN THIS FILE.  WW CAN ONLY
C          ATTACK RADARS FROM THIS FILE.
C
          NEXT=MMFE(1)
   10     IF(NEXT.EQ.0)GO TO 20
          CALL COPY(-NEXT,1,A)
          IF((A(2).EQ.4.OR.A(2).EQ.5.OR.A(2).EQ.6).AND.A(4).LT.50000)THEN
            CALL FILEM(2,A)
          ENDIF
          NEXT=NSUCR(NEXT)
          GO TO 10
```

```
20    CONTINUE
      CALL PRNTF(1)
      CALL PRNTF(2)
      RETURN
      END
```

```
      SUBROUTINE EVENT(IX)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLN
     &NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
     &TNOW,XX(100)
      DIMENSION REV(4),TOF(4),PK(4)
      COMMON/UCOM2/TL,TI,PKR,RI,SRR
      COMMON/UCOM1/RATE(2),L(2)
      DIMENSION A(16),C(16),F(16),G(16),EA(16),EB(16)
      I=ATRIB(1)
      IF(I.GT.200)THEN
        I=I-190
        J=I-20
        JW=(2*J)+1
        IR=(4*J)+11
        LF=I-4
      ENDIF
      IF(I.LE.10)LF=I+6
C
C        IF A RADAR OR AN AIRCRAFT IS KILLED IN THE
C        IMMEDIATE PRIOR EVENT, EVENT NODE "3" IS CALLED
C        TO ENSURE THE ENTITY IS REMOVED FROM THE PROGRAM.
C
      IF(IX.LT.14)THEN
        IF(ATRIB(1).EQ.XX(54).OR.ATRIB(1).EQ.XX(58))THEN
          CALL ENTER(3,ATRIB)
          RETURN
        ENDIF
      ENDIF
      GO TO(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,
     &16,17,18,19),IX
***********************************************************************
C
C        EVENT 1(WW NODE ONLY) - REALIZED WHEN A WW'S RANGE TO
C        RADAR DECREASED TO WW FIELD-OF-VIEW.
C
1     PRINT*,'EV 1 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
C        BASED ON POSITION AND HEADING OF WW TURN THE WW TO
C        START RANGING ROUTINE.
C
      IF(SS(I+24).GT.0.AND.SS(I+24).LT.180)THEN
       IF(SS(I+8).GT.SS(I+24).AND.SS(I+8).LT.(SS(I+24)+
     &180))THEN
          REV(J)=1.0
          IF(SS(I+28).LT.75.0)THEN
            RATE(J)=4.0
           ELSE
            RATE(J)=-4.0
          ENDIF
         ELSE
          REV(J)=2.0
```

```
                  IF(SS(I+28).LT.75.0)THEN
                  RATE(J)=-4.0
                 ELSE
                  RATE(J)=4.0
                ENDIF
               ENDIF
              ELSE
               IF(SS(I+8).GT.(SS(I+24)-180).AND.SS(I+8).LT.
     &SS(I+24))THEN
                REV(J)=2.0
                IF(SS(I+28).LT.75)THEN
                  RATE(J)=-4.0
                ELSE
                  RATE(J)=4.0
                ENDIF
               ELSE
                REV(J)=1.0
                IF(SS(I+28).LT.75.0)THEN
                 RATE(J)=4.0
               ELSE
                 RATE(J)=-4.0
               ENDIF
              ENDIF
             ENDIF
C       SET WW WORKING DESIGNATOR TO 1
        SS(I+12)=1.0
C
C       FOR THE RADAR THAT THE WW IS ATTACKING, SET ITS
C       14TH ATTRIBUTE EQUAL TO THE CALL SIGN OF THE WW.
C
        AL=L(J)
        NGET=NFIND(1,2,1,0,AL,0.0)
        CALL RMOVE(NGET,2,A)
        A(14)=ATRIB(1)
        CALL FILEM(2,A)
        CALL FILEM(JW,A)
        RETURN
*********************************************************************
C
C       EVENT 2(WW MODE ONLY) - REALIZED WHEN WW DETECTS 70 DEGREES
C       RELATIVE BEARING ON THE RADAR SITE IT IS ATTACKING. THIS
C       EVENT ROLLS THE WW OUT OF ITS TURN.
C
2       PRINT*,'EV 2 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
        RATE(J)=0.0
        RETURN
*********************************************************************
C
C       EVENT 3(WW MODE ONLY) - REALIZED WHEN WW DETECTS 105
C       DECREES RELATIVE BEARING ON THE RADAR IT IS WORKING.
```

```
C        THIS EVENT ROLLS THE WW BACK INTO THE SITE.
C
3     PRINT*,'EV 3 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
      IF(REV(J).EQ.1)RATE(J)=-4.0
      IF(REV(J).EQ.2)RATE(J)=4.0
      RETURN
*******************************************************************
C
C        EVENT 4(WW NODE ONLY) - REALIZED WHEN WW DETECTS 10 DEGREES
C        RELATIVE BEARING ON THE SITE IT IS ATTACKING. THIS EVENT
C        REDUCES THE TURN RATE OF THE WW.
C
4     PRINT*,'EV 4 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
      IF(REV(J).EQ.1)RATE(J)=-2.0
      IF(REV(J).EQ.2)RATE(J)=2.0
      RETURN
*******************************************************************
C
C        EVENT 5(WW NODE ONLY) - REALIZED WHEN WW IS BORESIGHTED ON
C        THE RADAR IT IS ATTACKING.  BASED ON THE POSITION OF THE
C        WW, A DECISION IS MADE OF WHETHER TO FIRE AN ARM.  IF
C        THE WW DECIDES IT WILL FIRE AN ARM, THEN THE PK OF THE
C        ARM IS DETERMINED AND THE FIRING RANGE OF THE ARM CAL-
C        CULATED.
C
5     PRINT*,'EV 5 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
C        IF WW HAS AGM-78S, THEN SELECT THAT TYPE ARM TO
C        FIRE(ATRIB(2) GREATER THAN 10). OTHERWISE SELECT
C        AN AGM-45.
      IF(ATRIB(2).GE.10)GO TO 40
C        RM45=MINIMUM LAUNCH RANGE OF AGM-45
      RM45=8000.0
C        XX(10)=MAXIMUM LAUNCH RANGE. IF RANGE TO TARGET IS
C        GREATER THAN 15000M, THEN USE 15000M AS MAXIMUM RANGE
C        FOR THE MISSILE.  IF THE ACTUAL RANGE TO THE TARGET
C        IS LESS THAN THE MINIMUM RANGE OF THE ARM, THEN DO
C        NOT COMPUTE PK; GO TO "REPOSITIONING ROUTINE."
      XX(10)=SS(I+16)
      IF(XX(10).GT.15000.0)XX(10)=15000.0
      IF(SS(I+16).LT.RM45)GO TO 42
C        XX(4)=ACTUAL FIRING RANGE OF ARM. TOF IS FLIGHT TIME OF
C        THE MISSILE FROM THE LAUNCH POINT TO IMPACT POINT.
      XX(4)=UNFRM(8000.0,XX(10),1)
      TOF(J)=XX(4)/350.0
      ATRIB(2)=ATRIB(2)-1
C        DETERMINE PK OF ARM
      SAMPLE=DRAND(1)
      IF(SAMPLE.LT..8)THEN
        PK(J)=1.0
       ELSE
```

```
              PK(J)=0.0
          ENDIF
          GO TO 41
C            CALCULATIONS FOR ACM-78
40        RM78=8000.0
          XX(10)=SS(I+16)
          IF(XX(10).GT.25000.0)XX(10)=25000.0
          IF(SS(I+16).LT.RM78)GO TO 42
          XX(4)=UNFRM(8000.0,XX(10),1)
          TOF(J)=XX(4)/450.0
          ATRIB(2)=ATRIB(2)-10.0
          SAMPLE=DRAND(1)
          IF(SAMPLE.LT..85)THEN
            PK(J)=1.0
           ELSE
            PK(J)=0.0
          ENDIF
41        CONTINUE
C            RLWW=TIME FOR THE WW TO GET FROM ITS PRESENT POSITION
C            TO ITS ARM FIRING RANGE.
          RLWW=((SS(I+16)*COS(ASIN(XX(3)/SS(I+16))))-XX(4))/XX(5))
          XX(IR)=RLWW
          XX(IR+1)=TOF(J)
          RATE(J)=0.0
          REV(J)=0.0
          RETURN
C            IF THE WW WAS TOO CLOSE TO FIRE THE ARM THEN START WW
C            TURNING FOR "REPOSITIONING ROUTINE."
42        RATE(J)=-4.0
          IF(REV(J).EQ.1)RATE(J)=4.0
          RETURN
*******************************************************************
C
C            EVENT 6(WW NODE ONLY) - REALIZED WHEN THE WW GETS TO ARM
C            FIRING RANGE. "ENTER NODE 1/2" CALLED FROM THIS EVENT IN
C            ORDER TO EVALUATE THE PK OF THE ARM AT IMPACT TIME.
C
6         PRINT*,'EV 6 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
          IF(J.EQ.1)THEN
            XX(17)=XX(17)+1.0
            P=XX(17)+84
            XX(P)=XX(IR+1)
           ELSEIF(J.EQ.2)THEN
            XX(21)=XX(21)+1.0
            P=XX(21)+89
            XX(P)=XX(IR+1)
          ENDIF
C            FIND THE RADAR IN FILE 2 THAT THE WW IS ATTACKING.
C            CALL ENTER NODE 1/2 WITH THE ATTRIBUTES OF THE RADAR
C            LOADED INTO THE ATRIB ARRY.
```

```
        AL=L(J)
      NCT=NFIND(1,2,1,0,AL,0)
      IF(J.EQ.1)THEN
        CALL COPY(NCT,2,EA)
        CALL ENTER(1,EA)
       ELSEIF(J.EQ.2)THEN
        CALL COPY(NCT,2,EB)
        CALL ENTER(2,EB)
      ENDIF
C       CHECK TO SEE IF WW OUT OF ARMS. IF IT IS THEN SET
C       WW WORKING DESIGNATOR EQUAL TO 9.
      IF(ATRIB(2).EQ.0)SS(I+12)=9.0
      RETURN
*******************************************************************
C
C        EVENT 7(WW NODE ONLY) - THIS EVENT OCCURS 5 SECONDS AFTER
C        THE WW LAUNCHES ARM.  WW WORKING DESIGNATOR IS SET TO 0
C        TO ALLOW THE WW TO BEGIN SEARCHING FOR A NEW RADAR TO
C        ATTACK.
C
7     PRINT*,'EV 7 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
      SS(I+12)=0.0
      RETURN
*******************************************************************
C
C        EVENT 8(WW NODE ONLY) - THIS EVENT ENTERS THE WW BACK INTO
C        THE NETWORK BASED ON ITS POSITION RELATIVE TO THE RADAR
C        SITE IT IS ATTACKING.
C
8     PRINT*,'EV 8 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
      IF(SS(I+16).LT.SS(I+20))THEN
        AL=L(J)
        NCET=NFIND(1,2,1,0,AL,0)
        CALL RMOVE(NCET,2,A)
        A(14)=ATRIB(1)
        CALL FILEM(2,A)
        CALL FILEM(JW,A)
        SS(I+12)=1.0
        IF(SS(I+24).GT.0.AND.SS(I+24).LT.180)THEN
          IF(SS(I+8).GT.SS(I+24).AND.SS(I+8).LT.(SS(I+24)+
     &180))THEN
            REV(J)=1.0
            IF(SS(I+28).LT.75)THEN
              RATE(J)=4.0
             ELSE
              RATE(J)=-4.0
            ENDIF
           ELSE
            REV(J)=2.0
            IF(SS(I+28).LT.75)THEN
```

```
                 RATE(J)=-4.0
                ELSE
                 RATE(J)=4.0
               ENDIF
              ENDIF
            ENDIF
           ELSE
            IF(SS(I+8).GT.(SS(I+24)-180).AND.SS(I+8).LT.SS(I+24))THEN
              REV(J)=2.0
              IF(SS(I+28).LT.75)THEN
                RATE(J)=-4.0
               ELSE
                RATE(J)=4.0
              ENDIF
             ELSE
              REV(J)=1.0
              IF(SS(I+28).LT.75)THEN
                RATE(J)=4.0
               ELSE
                RATE(J)=-4.0
              ENDIF
             ENDIF
            ENDIF
          RETURN
***********************************************************************
C
C       EVENT 9(WW NODE ONLY) - EVENT REALIZED FROM WW ENTER
C       NODE.  DETERMINES PK OF ARM AT THE END OF ARM'S FLIGHT
C       TIME.
C
9     PRINT*,'EV 9 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
      LF=ATRIB(14)-194
      J=ATRIB(14)-210
      JW=(2*J)+1
      PRINT*,'AT(14)= ',ATRIB(14),'LF= ',LF,'J= ',J
      NF2=NFIND(1,2,1,0,ATRIB(1),0)
      IF(NF2.EQ.0)RETURN
      NF=NFIND(1,JW,1,0,ATRIB(1),0)
      IF(NF.EQ.0)RETURN
      NF1=NFIND(1,1,1,0,ATRIB(1),0)
      PRINT*,'NF1= ',NF1
      IF(NF1.EQ.0)RETURN
C       IF THE WW KILLS THE RADAR, THEN THE RADAR IS CHECKED
C       TO SEE IF IT WAS A EW/GCI RADAR. IF IT WAS, THEN ALL
C       ASSOCIATED RADARS THAT USE THIS EW/GCI FOR ACQUISITION
C       AND TRACKING HAVE THEIR 5TH ATTRIBUTE SET TO 10.
C       THE "DEAD" RADAR IS REMOVED FROM FILE 1,FILE 2 AND THE
C       WEASEL'S WORKING FILE. XX(49) IS SET EQUAL TO THE
C       RADAR'S SEQUENTIAL NUMBER(ATRIB(1) FOR THIS EVENT).
C       THE RADAR IS REMOVED FROM THE EVENT CALENDAR.
```

```
          IF(PK(J).EQ.1)THEN
            PRINT*,'RADAR ',ATRIB(1),' KILLED BY WW ',ATRIB(14)
            CALL RMOVE(NF1,1,A)
            PRINT*,'A(1)= ',A(1)
            CALL RMOVE(NF,JW,A)
            IF(A(2).EQ.6)THEN
              DO 66 IT=1,NNQ(1)
              CALL COPY(IT,1,C)
              IF(A(5).EQ.C(5))THEN
                CALL RMOVE(IT,1,C)
                C(5)=10.0
                CALL FILEM(1,C)
              ENDIF
66            CONTINUE
            ENDIF
            CALL FILEM(JW+1,A)
            CALL RMOVE(NF2,2,A)
            XX(49)=ATRIB(1)
91        NREM=NFIND(1,NCLNR,3,0,ATRIB(1),0)
          IF(NREM.GT.0)THEN
            CALL ULINK(NREM,NCLNR)
            GO TO 91
          ENDIF
C            IF THE RADAR IS NOT KILLED, IT IS REMOVED FROM THE WW'S
C            WORKING FILE AND ITS 14TH ATTRIBUTE IS RESET TO 0 IN
C            FILE 2.
           ELSEIF(PK(J).EQ.0)THEN
            CALL RMOVE(NF,JW,A)
            CALL RMOVE(NF2,2,A)
            A(14)=0.0
            CALL FILEM(2,A)
          ENDIF
          RETURN
*******************************************************************
C
C          EVENT 10(WW NODE ONLY) - REPOSITIONING ROUTINE.
C          EVENT REALIZED WHEN WW TURNS 179 DEGREES ABSOLUTE
C          RELATIVE BEARING FROM SITE IT IS ATTACKING.
C          EVENT ROLLS WW OUT OF TURN.
C
10        PRINT*,'EV 10 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
          RATE(J)=0.0
          RETURN
*******************************************************************
C
C          EVENT 11(WW NODE ONLY) - REPOSITIONING ROUTINE.
C          EVENT REALIZED WHEN WW DETECTS REQUIRED RANGE FROM
C          SITE IT IS ATTACKING. EVENT ROLLS WW BACK INTO TURN.
C
11        PRINT*,'EV 11 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
```

```
      RATE(J)=-4.0
      IF(REV(J).EQ.1)RATE(J)=4.0
      RETURN
**********************************************************************
C
C        EVENT 12(WW NODE ONLY) - WW SENT HOME.
C        THIS EVENT SENDS THE WW HOME AFTER IT FIRES ALL
C        OF ITS ARMS.
C
12    PRINT*,'EV 12 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
      RATE(J)=4.0
      REV(J)=1.0
      RETURN
**********************************************************************
C
C        EVENT 13(WW NODE ONLY) - WW SENT HOME.
C        THIS EVENT ROLLS WW OUT AFTER ITS INITIAL TURN HOME.
C
13    PRINT*,'EV 13 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
      RATE(J)=0.0
      RETURN
**********************************************************************
C
C        EVENT 14(ALL AIRCRAFT) - THIS EVENT APPLIES FOR ALL
C        AIRCRAFT. IT SIMULATES RADARS SEARCHING FOR AIRCRAFT.
C        A CHECK IS FIRST MADE TO ENSURE THAT NO MORE THAN
C        5 RADARS ARE ENGAGED WITH THE AIRCRAFT. IF THERE ARE
C        5 RADARS ALREADY WORKING THE AIRCRAFT THEN THE EVENT
C        IS BY-PASSED. OTHERWISE SUBROUTINE SEARCH IS CALLED.
C
14    IF(SS(1).GT.145000.AND.ATRIB(1).LT.200)THEN
        XX(55)=ATRIB(1)
        RETURN
      ENDIF
      IF(NNQ(LF).EQ.5)RETURN
      CALL SEARCH
      RETURN
**********************************************************************
C
C        EVENT 15(ALL AIRCRAFT) - EVENT REALIZED AT THE END OF
C        TRACKING AND ACQUISITION TIME. SUBROUTINE PROB IS CALL-
C        ED TO DETERMINE PK, TI(TIME OF INTERCEPT), TL(TIME OF
C        LAUNCH). BASED ON THESE VALUE THE FOLLOWING CAN OCCUR.
C          1)  EVENT 16 IS SCHEDULED AT ESTIMATED LAUNCH TIME.
C          2)  EVENT 17 IS SCHEDULED AT ESTIMATED IMPACT TIME.
C          3)  EVENT 19 IS SCHEDULED TO OCCUR IN 30 SECONDS BAS-
C              ED ON A LOW VALUE OF PK.
C
15    PRINT*,'EV 15 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
      CALL PROB
```

```
          IF(PKR.LT..05)THEN
            CALL SCHDL(19,30.0,ATRIB)
            RETURN
          ENDIF
          NP1=NFIND(1,1,1,0,ATRIB(3),0)
          PRINT*,'NP1= ',NP1
          IF(NP1.EQ.0)THEN
            CALL SCHDL(19,30.0,ATRIB)
            RETURN
          ENDIF
          CALL COPY(NP1,1,A)
          ATRIB(4)=TL
          ATRIB(5)=TI
          ATRIB(6)=PKR
          ATRIB(7)=A(6)
          ATRIB(8)=A(3)
          ATRIB(9)=A(4)
          IF(TNOW.EQ.TL)THEN
            ATRIB(10)=RI
            T=TI-TNOW
            CALL SCHDL(17,T,ATRIB)
           ELSE
            T=TL-TNOW
            CALL SCHDL(16,T,ATRIB)
          ENDIF
          RETURN
************************************************************
C
C          EVENT 16(ALL AIRCRAFT) - EVENT REALIZED AT ESTIMATED
C          MISSILE LAUNCH TIME. SUBROUTINE PROB IS CALLED TO DE-
C          TERMINE NEW PK AND TI. BASED ON THESE VALUES EITHER
C          EVENT 19 IS SCHEDULED(PK TOO LOW) OR EVENT 17 IS
C          SCHEDULED AT MISSILE IMPACT TIME.
C
16        PRINT*,'EV 16 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
          CALL PROB
          IF(PKR.LT..05)THEN
            CALL SCHDL(19,30.0,ATRIB)
            RETURN
          ENDIF
          ATRIB(6)=PKR
          ATRIB(5)=TI
          ATRIB(10)=RI
          TT=TI-TNOW
          CALL SCHDL(17,TT,ATRIB)
          RETURN
************************************************************
C
C           EVENT 17(ALL AIRCRAFT) - EVENT REALIZED AT MISSILE IMPACT
C           TIME. SUBROUTINE PROB IS CALLED TO DETERMINE PK AND NEW
```

```
C         TI. IF THE AIRCRAFT HAS TURNED AWAY FROM THE RADAR
C         SITE("RATIO" GREATER THAN 1.1) THEN ANOTHER ITERATION
C         IS MADE AND EVENT 17 IS SCHEDULED AT THE TIME IT TAKES
C         FOR THE AIRCRAFT TO MOVE TO THE NEW TI. OTHERWISE, THE
C         KILL/NOT KILL IS EVALUATED BASED ON MONTE CARLO DRAW.
C
17    PRINT*,'EV 17 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
      PRINT*,'ATRIB(3)= ',ATRIB(3)
      CALL PROB
        T=((ATRIB(5)-ATRIB(4))*SRR)/ATRIB(10)
      RATIO=SRR/ATRIB(10)
      IF(RATIO.GT.1.1)THEN
        ATRIB(6)=PKR
        CALL SCHDL(17,T,ATRIB)
        RETURN
      ENDIF
      SAMPLE=DRAND(1)
      IF(SAMPLE.LE.ATRIB(6))THEN
        PRINT*,'AIRCRAFT ',ATRIB(1),' KILLED BY RADAR ',ATRIB(3)
      IF(ATRIB(1).GT.200)THEN
        XX(59)=XX(59)+1.0
        IF(ATRIB(1).EQ.211)XX(54)=ATRIB(1)
        IF(ATRIB(1).EQ.212)XX(58)=ATRIB(1)
      ENDIF
        IF(ATRIB(1).LT.200)XX(57)=XX(57)+1.0
55    NREM=NFIND(1,NCLNR,1,0,ATRIB(1),0)
      IF(NREM.GT.0)THEN
       CALL ULINK(NREM,NCLNR)
       GO TO 55
      ENDIF
      ATRIB(6)=1.0
      ENDIF
      CALL SCHDL(18,30.0,ATRIB)
      RETURN
**************************************************************
C
C        EVENT 18(ALL AIRCRAFT) - EVENT OCCURS 30 SECONDS AFTER
C        MISSILE IMPACT. BASED ON WHETHER THE AIRCRAFT WAS KILLED/
C        NOT KILLED RADAR(S) ARE FREED TO BEGIN NEW SEARCH.
C
18    PRINT*,'EV 18 TNOW= ',TNOW,' ATRIB(1)= ',ATRIB(1)
      IF(ATRIB(6).NE.1)THEN
C        IF THE AIRCRAFT WAS NOT KILLED THEN ONLY FREE THAT RADAR
C        THAT WAS SHOOTING.
       NC=NFIND(1,LF,1,0,ATRIB(3),0)
      IF(NC.EQ.0)GO TO 200
        CALL RMOVE(NC,LF,A)
      NC1=NFIND(1,1,1,0,ATRIB(3),0)
      PRINT*,'NC1= ',NC1
        IF(NC1.EQ.0)GO TO 200
```

```
              CALL RMOVE(NC1,1,A)
              A(8)=0.0
              CALL FILEM(1,A)
      200   RETURN
             ELSE
      C        IF THE AIRCRAFT WAS KILLED THEN FREE ALL RADARS TRACK-
      C        ING IT.
      102     NR=NFIND(1,LF,8,0,ATRIB(1),0)
              IF(NR.GT.0)THEN
                CALL RMOVE(NR,LF,A)
                GO TO 102
              ENDIF
      103     NR1=NFIND(1,1,8,0,ATRIB(1),0)
              IF(NR1.GT.0)THEN
                CALL RMOVE(NR1,1,A)
                A(8)=0.0
                CALL FILEM(1,A)
                GO TO 103
              ENDIF
            ENDIF
            RETURN
      ****************************************************************
      C
      C        EVENT 19(ALL AIRCRAFT) - EVENT IS SCHEDULED FROM EVENTS
      C        15 OR 16 WHEN THE CALCULATED PK IS DETERMINED TOO LOW
      C        FOR THE RADAR TO CONTINUE TRACKING.
      C
      19    PRINT*,'EV 19 TNOW=',TNOW,'AT(1)=',ATRIB(1),'AT(3)=',ATRIB(3)
            NP=NFIND(1,LF,1,0,ATRIB(3),0)
            PRINT*,'NP= ',NP
            CALL RMOVE(NP,LF,A)
            NP=NFIND(1,1,1,0,ATRIB(3),0)
            PRINT*,'NP= ',NP
            CALL RMOVE(NP,1,A)
            A(8)=0.
            CALL FILEM(1,A)
            RETURN
            END
      ****************************************************************
      ****************************************************************
      C
      C        SUBROUTINE SEARCH IS CALLED BY EVENT 14. THIS SUBROUTINE
      C        SIMULATES THE SEARCHING BY RADARS FOR AIRCRAFT. BASED ON
      C        VARIOUS PARAMTERS THE RADAR WILL DETECT THE AIRCRAFT AND
      C        SCHEDULE TRACKING AND ACQUISITION TIME.
      C
            SUBROUTINE SEARCH
            COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
           &NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
           &TNOW,XX(100)
```

```
      COMMON/UCOM1/RATE(2),L(2)
      COMMON/UCOM3/SAM(5,12)
      DIMENSION A(16),B(16),BA(16)
      I=ATRIB(1)
      IF(I.LT.200)THEN
        ALT=XX(13)
        YPOS=XX(60+I)
        LF=I+6
       ELSE
        I=I-190
        J=I-20
        YPOS=SS(I+4)
        ALT=XX(3)
        LF=I-4
      ENDIF
      SRMP=ALT/SIND(0.25)
      LL=MMFE(1)
 25   CALL COPY(-LL,1,BA)
C        IF THE RADAR IS AN EW/GCI
      IF(BA(2).EQ.6)GO TO 27
C        OR IF THE AIRCRAFT'S ALTITUDE IS BELOW RADAR COVERAGE
      IF(ALT.LT.BA(7))GO TO 27
C        OR IF THE RADAR IS ALREADY ENGAGED
      IF(BA(8).GT.0)GO TO 27
C        OR IF THE RADAR IS SHUTDOWN >>>> GO TO THE NEXT RADAR
      IF(BA(9).EQ.0)GO TO 27
      X=BA(3)
      Y=BA(4)
      SR=SQRT((X-SS(I))**2+(Y-YPOS)**2+ALT**2)
C        IF THE RANGE TO THE AIRCRAFT IS LESS THAN MULTI-PATH
      IF(SR.GT.SRMP)GO TO 27
C        OTHERWISE, IF THE RANGE IS LESS THAN THE MAXIMUM RANGE
      IF(SR.LT.BA(6))THEN
        BA(8)=ATRIB(1)
        CALL FILEM(LF,BA)
        CALL RMOVE(-LL,1,A)
        CALL FILEM(1,BA)
      PRINT*,'A(1)= ',A(1),' BA(1)= ',BA(1)
        IT=BA(2)
C        DETERMINE ACQUISITION AND TRACKING TIME BASED ON UNIFORM
C        DISTRIBUTION UNLESS THE RADAR'S ASSOCIATED EW/GCI WAS
C        KILLED(BA(5)=10) - IN THAT CASE USE ONLY THE HIGH TIME.
        TL=SAM(IT,7)
        TH=SAM(IT,8)
        TRC=UNFRM(TL,TH,1)
        IF(BA(5).EQ.10)TRC=TH
        B(1)=ATRIB(1)
        B(3)=BA(1)
        CALL SCHDL(15,TRC,B)
      ENDIF
```

```
      IF(NNQ(LF).EQ.5)GO TO 26
27    LL=NSUCR(LL)
      IF(LL.NE.0)GO TO 25
26    CONTINUE
      RETURN
      END
*********************************************************************
*********************************************************************
C
C        SUBROUTINE PROB - THIS SUBROUTINE CALCULATES THE PK'S
C        FOR THE APPROPRIATE SYSTEM, AS WELL AS THE TIME OF LAUNCH
C        (TL) AND TIME OF IMPACT(TI).
C
      SUBROUTINE PROB
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
     &NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
     &TNOW,XX(100)
      COMMON/UCOM2/TL,TI,PKR,RI,SRR
      COMMON/UCOM1/RATE(2),L(2)
      DIMENSION A(16),B(16),BA(16)
      COMMON/UCOM3/SAM(5,12)
      DATA((SAM(IA,JA),JA=1,12),IA=1,5)/
     &0,0,0,0,0,0,6,25,0,-47.6,0,30,
     &2.52E-5,9610,671,7.3E-27,6.36E-17,671,18,51,592,-46.2,56.4,
     &13,
     &5.62E-6,2500,232,7.3E-27,6.36E-17,232,12,26,759,-51.4,43.6,
     &15,
     &7.1E-7,2200,58,4.03E-27,1.02E-16,58,17,38,599,-53.4,26.2,
     &30,
     &3.25E-7,1890,25,8.09E-27,4.84E-16,25,10,23,525,-52.4,22,30/
      I=ATRIB(1)
      IF(I.LT.200)THEN
        YPOS=XX(60+I)
        ALT=XX(13)
        VEL=XX(14)
        HDG=90.0
       ELSE
        I=I-190
        J=I-190
        HDG=SS(I+8)
        YPOS=SS(I+4)
        ALT=XX(3)
        VEL=XX(5)
      ENDIF
      SRMP=ALT/SIND(0.25)
      IF(I.LE.10)LF=I+6
      IF(I.GT.10)LF=I-4
C        GET THE FILE OF THE AIRCRAFT BEING ATTACKED.
      NC=NFIND(1,LF,1,0,ATRIB(3),0)
      CALL COPY(NC,LF,A)
```

```
      X=A(3)
      Y=A(4)
      SR=SQRT((X-SS(I))**2+(Y-YPOS)**2+ALT**2)
      ANGN=57.3*ASIN(ALT/SR)
      SRN=SR*COSD(ANGN)
C        IF THE RANGE IS GREATER THAN MULTI-PATH OR GREATER THAN
C        MAXIMUM RANGE OF THE THREAT SET PK EQUAL TO 0.
      IF(SR.GT.SRMP.OR.SR.GT.A(6))THEN
        PKR=0.0
        RETURN
      ENDIF
      SRR=SR
C        IF THE THREAT IS A AAA GO TO AAA ROUTINE(99)
      IF(A(2).EQ.1)GO TO 99
C        DETERMINE ASPECT ANGLE OF THREAT/AIRCRAFT.
      D=(Y-YPOS)/(X-SS(I))
      YT=Y-YPOS
      IF(D.GE.0.AND.YT.GE.0)THEN
        FANG=57.3*ATAN(1/D)
       ELSEIF(D.LT.0.AND.YT.GE.0)THEN
        FANG=270+57.3*ABS(ATAN(D))
        ELSEIF(D.LT.0.AND.YT.LT.0)THEN
        FANG=90+57.3*ABS(ATAN(D))
       ELSEIF(D.GE.0.AND.YT.LT.0)THEN
        FANG=270-57.3*ATAN(D)
      ENDIF
      ANG=ABS(FANG-HDG)
      IF(ANG.GT.180)ANG=360-ANG
C        IF THE ANGLE(ANG) IS LESS THAN 90 DEGREES THEN THE
C        AIRCRAFT IS IN FRONT OF THE THREAT. CALCULATE PARA-
C        METERS TO OBTAIN TI AND TL.
      IF(ANG.LT.90)THEN
        RC=SR*SIND(ANG)
        AB=SR*COSD(ANG)
        TIMAC=AB/VEL
        TMFO=RC/SAM(A(2),9)
        IF(TIMAC.GE.TMFO)THEN
          TL=TNOW+TIMAC-TMFO
          TI=TMFO+TL
          RI=RC
         ELSE
          RI=SQRT(((TMFO-TIMAC)*VEL)**2+RC**2)
          TL=TNOW
          TI=TL+(RI/SAM(A(2),9))
        ENDIF
       ELSE
        ANG2=180-ANG
        RC=SQRT((SRN*SIND(ANG))**2+ALT**2)
        VR=VEL/(SAM(A(2),9))
        E=1.0-(VR**2)
```

```
          F=-(2*SRN*VR*COSD(ANC))
          G=SQRT((F**2)+(4*E*(SRN**2)))
          RI=(G-F)/(2*E)
        RI=SQRT(RI**2+ALT**2)
          TL=TNOW
          TI=TL+(RI/SAM(A(2),9))
        ENDIF
        TRCS=180-57.3*(ASIN(RC/RI))
        IJ=A(2)
        ICET=NFIND(1,19,1,0,TRCS,2.51)
        CALL COPY(ICET,19,B)
        JR=IJ+1
        SIGMA=B(JR)
        IF(RI.GE.A(6))THEN
          PKR=0.0
         ELSE
          IF(ATRIB(1).LT.200)THEN
            AJSBDW=SAM(A(2),10)+20*ALOG10(RI)-SIGMA
            AJS=10**(AJSBDW/10)
            CEP=SQRT((((SAM(A(2),1)*AJS*(RI**2))+SAM(A(2),2)*AJS)+
      &SAM(A(2),3)))
           ELSE
            SIGM2=10**(SIGMA/10)
            CEP=SQRT(((SAM(A(2),4)*(RI**6)/SIGM2)+(SAM(A(2),5)*
      &(RI**4)/SIGM2)+SAM(A(2),6)))
          ENDIF
          PKR=1.0-(.5**(((SAM(A(2),11)/CEP)**2)))
          IF(PKR.LT..02)PKR=0.0
        ENDIF
        RETURN
 99     IF(ATRIB(1).GT.200)THEN
          IF(RATE(J).NE.0)THEN
            G=2.0
           ELSE
            G=1.3
          ENDIF
         ELSE
           IF(SS(I).GT.45000.0.AND.SS(I).LT.65000.0)THEN
             G=2.0
            ELSE
             G=1.3
           ENDIF
        ENDIF
        SRK=SR/1000.0
        SIGAAA2=(20*SRK)**2.0
        VF=930.0*EXP(-.4965*SRK)
        TOFL=(2014.46/VF)-2.166
        TI=TNOW+TOFL
        DA=(2.*3.14159*SIGAAA2)+5.1727
        PKSS=(5.1727/DA)*EXP((-.5*(9.8*G*(TOFL**2.))**2.0)/DA)
```

```
      PKR=1.0-((1.0-PKSS)**50.)
      TL=TNOW
      RETURN
      END
*************************************************************************
*************************************************************************
      SUBROUTINE OTPUT
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR,
     &NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
     &TNOW,XX(100)
      PRINT*
      PRINT*
      PRINT*,'ATTACK AIRCRAFT SURVIVING= ',XX(56)
      PRINT*,'ATTACK AIRCRAFT KILLED    = ',XX(57)
      PRINT*,'RADARS KILLED BY WW       = ',XX(58)
      PRINT*,'WW KILLED                 = ',XX(59)
      RETURN
      END
```

Appendix H

Two-Way ANOVA

The SPSS program for the two-way ANOVA was run with the data contained on the following page. The first column is the number of aircraft surviving and reaching the target area for the run, the next column the level for the factor of altitude (1=60m, 2=200m), and the last column the level for the factor of tactic (1=ahead of the attack force, 2= with the attack force). The overall results for the ANOVA are listed on the page following the data. There were no significant main effects or interactions.

1	3	1	1
2	1	1	1
3	1	1	1
4	5	1	1
5	4	1	1
6	4	2	1
7	4	2	1
8	3	2	1
9	3	2	1
10	2	2	1
11	3	1	2
12	1	1	2
13	0	1	2
14	2	1	2
15	3	1	2
16	5	2	2
17	1	2	2
18	4	2	2
19	1	2	2
20	3	2	2

SPSS Input Data

VOGELBACK COMPUTING CENTER
NORTHWESTERN UNIVERSITY

S P S S - - STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES

* * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * * *

SURVIVE
BY ALT   1=60M,2=200M
TACTIC   1=AHEAD,2=WITH

* *

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	4.900	2	2.450	1.114	.353
ALT	2.450	1	2.450	1.114	.307
TACTIC	2.450	1	2.450	1.114	.307
2-WAY INTERACTIONS	.450	1	.450	.205	.657
ALT TACTIC	.450	1	.450	.205	.657
EXPLAINED	5.350	3	1.783	.811	.506
RESIDUAL	35.200	16	2.200		
TOTAL	40.550	19	2.134		

20 CASES WERE PROCESSED.

Appendix I

Validation

WW Attack Profile Validation

This appendix contains the validation of the WW attack profile. As the WW proceeds through the threat environment hunting for radars to attack, the logic associated with its profile and the necessary computations that change the WW's behavior in the attack are hand-calculated and compared to computer output data. A typical WW attack is followed as the WW moves from one logic event to the next.

To hand-calculate the required parameters an encounter geometry is defined in the encounter diagram. Position 1 (x_1, y_1) depicts the WW in the FEBA geometry as it begins a turn and Position 2 (x_2, y_2) when it rolls out. The WW's flight distance from Position 1 to 2 is given by the following formula:

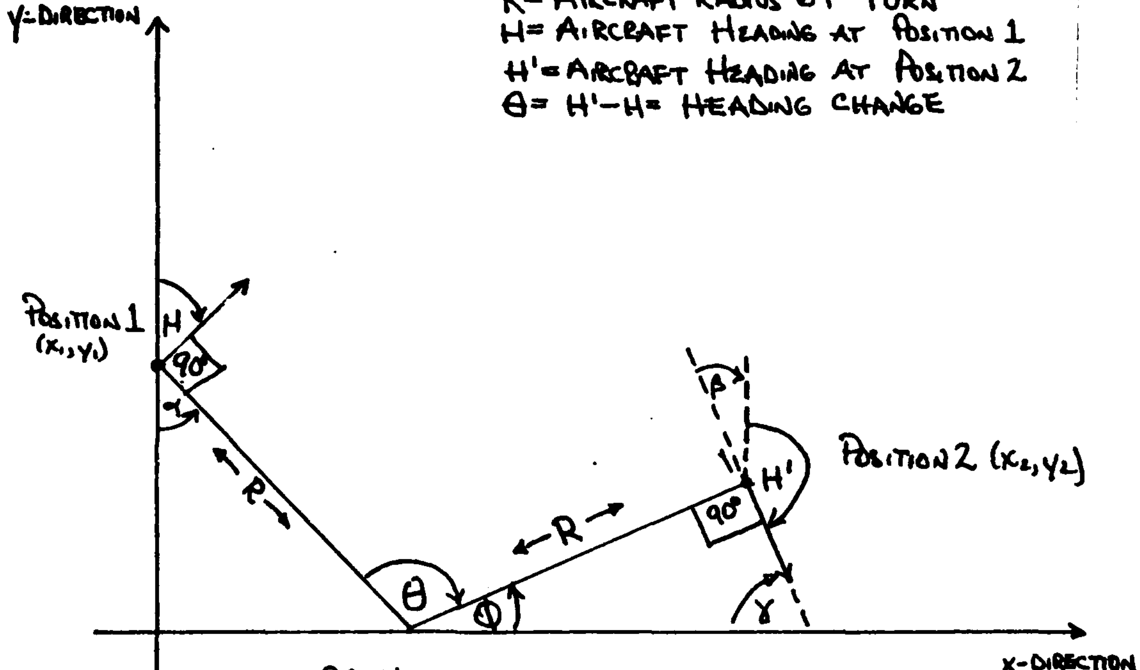
$$S = R\theta$$

where s = distance WW flies from 1 to 2,

R = WW's radius of turn, and

θ = number of degrees WW turns from 1 to 2 (in radians).

R = AIRCRAFT RADIUS OF TURN
H = AIRCRAFT HEADING AT POSITION 1
H' = AIRCRAFT HEADING AT POSITION 2
θ = H' − H = HEADING CHANGE



$\alpha = 90 - H$
$\beta = 180 - H'$
$\gamma = 90 - \beta = H' - 90$
$\phi = 90 - \gamma = \beta$
$\therefore \quad X_2 = X_1 + R \sin\alpha + R\cos\phi$
$\quad\quad Y_2 = Y_1 - (R\cos\alpha - R\sin\phi)$

The radius of turn R for an aircraft is given by:

$$R = \frac{v}{TR}$$

where R = radius of turn,

v = aircraft velocity, and

TR = aircraft turn rate in radians per second.

Thus for the WW with a velocity of 247 m/sec and a turn rate of 4 degrees/sec, R is given by:

$$R = \frac{247}{4 \times \frac{2\pi}{360}} = 3538 \text{ m}$$

For a turn rate of 2 degrees per second, R = 7076 m.

By knowing the WW's position when it starts its turn, the number of degrees of heading change, and the radius of turn R, then Position 2, the rollout point, can be determined.

WW1, call sign 211, is followed on its attack profile as it hunts for threats to attack, detects a threat, performs a ranging routine, launches an ARM, and begins a new engagement sequence. Output data from the computer simulation is listed at the end of this appendix.

WW1 enters the threat scenario at time TNOW = 0, x and y coordinates at (0, 25110), heading 090, altitude

60 m. Its radar horizon or line-of-sight range is given by equation (2):

$$h = 4117.3\sqrt{60} = 31892$$

The closest radar that WW can attack is radar 64 located at (52500, 25139). (See Appendix J for radar coordinates.) WW1 will proceed across the FEBA until the distance to radar 64 is detected to be less than the radar horizon distance at which time event 1 will be called. From the computer output event 1 is realized as TNOW = 84. WW1's position at that time

$$x = 247 \times 84 = 20748$$

$$y = 25110$$

The distance to radar 64 is given by equation (14):

$$SR = \sqrt{(20748 - 52500)^2 + (25110 - 25139)^2 + 60^2}$$

$$= 31752$$

Event 1 occurs at the correct time and position.

Event 1 starts the WW ranging routine turning the WW away from radar 64 at a turn rate of 4 degrees/second. At event 1 WW1's relative bearing to radar 64 is given by equation (11):

$$R = \tan^{-1}\left[\frac{52500-20748}{25140-25110}\right] = 89.9°$$

Event 2 occurs at TNOW = 102 and the absolute relative bearing to the site should be 75 degrees. The heading change from event 1 to event 2 is given by equation (10):

$$\theta = (102-84) \times 4°/\text{sec} = 72°$$

Its new heading at TNOW = 102 should be:

$$H = 90° + 72° = 162°$$

From the encounter geometry, the position of WW1 at event 2 should be:

$$x = 20748 + 3538 \cos 18° = 24113$$

$$y = 25110 - [3538 + 3538 \sin 18°] = 22665$$

Relative bearing to radar 64 at this point is, by equation (11):

$$R = \tan^{-1}\left[\frac{52500-24113}{25140-22665}\right] = 85°$$

The absolute relative bearing is given by equation (12):

$$AB = (162 - 85) = 77°$$

These figures all agree with the output data.

Event 3 occurs when the absolute relative bearing is 105 degrees. The output data lists TNOW = 159 for event 3. The position of WW1 at this time is given by equations (35) and (46):

$$x = 24110 = 247 \sin 162 \times (159\text{-}102) = 28461$$

$$y = 22670 + 247 \cos 162 \times (159\text{-}102) = 9280$$

The relative bearing to radar 64, by equation (11) is:

$$R = \tan^{-1}\left[\frac{52500-28461}{25140-9280}\right] = 56.6°$$

The absolute relative bearing, given by equation (12), is:

$$AB = (162 - 56.6) = 105.4°$$

Hand-calculations confirm output data.

Event 4 occurs when the absolute relative bearing is 10 degrees. Event 3 should turn the WW back towards the site at 4 degrees/second. Event 4 occurs at TNOW = 186. The heading change is given by equation (10):

$$\theta = (186 - 159) \times 4°/\text{sec} = 108°$$

WW1's heading at event 4 should be:

$$H = 162 - 108 = 54°$$

From the encounter geometry WW1's position is calculated:

$$x = 28460 + 3538(\cos 18 + \cos 54) = 33908$$

$$y = 9279 + 3538(\sin 54 - \sin 18) = 7510$$

Relative bearing to radar 64 at this point, by equation (11):

$$R = \tan^{-1}\left[\frac{52500-33908}{25140-7510}\right] = 46.5°$$

Absolute relative bearing is given by equation (12):

$$AB = (54 - 46.5) = 7.5°$$

All calculations agree with the output data.

Event 5 occurs when WW1 is boresighted on radar 64 (absolute relative bearing zero). Event 4 turns the WW into the threat at a rate of 2 degrees/second. When event 5 occurs at TNOW = 190, heading change is given by equation (10):

$$\theta = (190 - 180) \times 2°/\text{sec} = 8°$$

WW1's heading should be:

$$H = 54 - 8 = 46°$$

From the encounter geometry the WW position is:

$$x = 33910 + 7076(\sin 44 - \sin 36) = 34618$$

$$y = 7510 + 7076(\cos 36 - \sin 46) = 8146$$

Relative bearing from equation (11) is:

$$R = \tan^{-1}\left[\frac{52500-34618}{25140-8146}\right] = 46.4$$

The absolute relative bearing, equation (12), is:

$$AB = (46 - 46.5) = 0.5°$$

These calculations agree with the output data.

Event 5 calculates the ARM release time and position, the time of flight for the ARM (TOF), and draws a random sample to evaluate the probability of kill of the ARM. WW1's distance to radar 64 at event 5 is given by equation (14):

$$SR = \sqrt{(34660 - 52500)^2 + (8144 - 25140)^2 + 62^2}$$
$$= 24639$$

The ARM release point for the WW is taken from a uniform distribution of low value equal to minimum range for the ARM and high value equal to the maximum ARM range or distance to the threat, whichever smaller (as long as ARM is within range of the threat). Computer output sets the release point, XX(4), equal to 24597. The time for WW1 to reach this point from its present position is:

$$\text{Time} = \text{Distance to Release/WW Velocity}$$

$$= \frac{(24639 - 24597)}{247} = 0.17 \text{ sec}$$

The TOF for the ARM is:

$$\text{TOF} = \text{ARM Distance/ARM Velocity}$$
$$= 24597/450 = 54.67$$

WW1 will kill radar 64 if the random sample drawn is less than or equal to 0.85, the ARM PK. Event 5 indicates that the random sample drawn is 0.6045. Calculations in event 5 concur with computer data.

Event 6 occurs when WW1 launches the ARM at radar 64. Hand calculations predict this should happen at event 5 time plus the time for WW1 to get from event 5's position to the ARM release point:

$$\text{TNOW(Event 6)} = 190 + 0.17 = 190.17$$

This agrees with the output data.

Event 9 simulates ARM impact and should occur when the ARM launched by WW1 reaches radar 64. This time should be:

$$\begin{aligned}\text{TNOW(Event 9)} &= \text{TNOW(Event 6)} + \text{TOF}\\ &= 190.15 + 54.67 = 244.82\end{aligned}$$

Since the sample drawn in event 5 was less than 0.85, the threat should be killed, as in fact it is according to the output data.

After WW1 fires the ARM it should be released 5 seconds later to start another engagement. Output data concurs with this.

As evidenced by the above comparisons between computer output data and hand-calculations, the WW attack profile is validated.

INTERMEDIATE RESULTS

EV 1 TNOW=84 ATRIB(1)=211 RADAR 64 IS ENGAGED
EV 2 TNOW=102 ATRIB(1)=211
EV 3 TNOW=159 ATRIB(1)=211
EV 4 TNOW=186 ATRIB(1)=211
EV 5 TNOW=190 ATRIB)1)=211
XX(10)=24635 XX(4)=24597
TOF=54.67 SAMPLE=.6045
PK=1 RLWW=.1545
EV 6 TNOW=190.154 ATRIB(1)=211
EV 7 TNOW=195.154 ATRIB(1)=211
EV 8 TNOW=195.254 ATRIB(1)=211
EV 2 TNOW=207 ATRIB(1)=211
EV 9 TNOW=244.8 ATRIB(1)=64
RADAR 64 KILLED BY WW 211

TABLE NUMBER 1

TIME	XPOS	YPOS	HDNG	RNGE	RLBR	ABRLB
0	0	25110	90	0	0	0
84	20750	25110	90	31750	89.96	.039
102	24110	22670	162	28490	85	77.0
159	28460	9279	162	28800	56.6	105.4
186	33910	7510	54	25620	46.5	7.5
190	34660	8144	46	24640	46.4	.4
195	35550	9002	46	23400	46.4	.4
207	36680	11650	359	18920	75.5	76.5

SAM and AAA Probability of Kill Validation

Event 15 (at the end of acquisition and tracking), event 16 (scheduled missile launch time), event 17 (scheduled missile impact time), and event 18 (freeing the threat radar 30 seconds after impact) represent the discrete events associated with the defensive network. Validating this portion of the model involves computing the variables required to estimate the P_k and comparing them with a computer printout of model derived parameters. A set of calculations for both SAM and AAA systems will be developed.

The calculations list the variable, followed by the computer variable for the quantity when the two are different. For example,

$$t_{AC}\,(\text{TIMAC}) = \frac{SR_{xy} \cos \theta}{V_m}$$

where "t_{AC}" is the notation for the time required for the aircraft to reach point "C" in the thesis and "TIMAC" is the computer variable of the same quantity.

SAM Calculations

Strike aircraft "1" was in threat "54"'s field of view (FOV) at TNOW = 32. Aircraft "1" was created at TNOW = 30 and Subroutine SEARCH assigned site "54" to it at

SAM Probability of Kill Computer Printout

(a) Subroutine SEARCH detects an aircract

```
RADAR ... START TRACKING ACFT 1.
AT TIME 32.
TRC= 23.2654688582 5
```

(b) Event 15: At the end of Acquisition and Tracking

```
EV 15 TNOW= 55.2654685825 ATRIB(1)= 1.
RADAR NUMBER 54.
YPOS= 24591.66242727 ALT= 31 . VEL= 247.
HDG= 9 . SRMP= 71146.392 3503 LG= 7
X= 5 . Y= 26361.83873 39 SR= 53796.41362336 D= .3664834388765
ANG= 2. 3241592162 RC= 198 . 6 23345 TIMAC= 217.6 4 2 5773
TMFO= 2.319867198 82 TLO 27 .239646338 TI= 272.919 93335
RI= 1998.466 23345 TRCS= 8 .99337 47465 SIGMA= 25.
PKR= .9 282 382261 CEP= 21.478 36 5966
EV 15 TNOW= 55.5875615 6515 ATRIB(1)= 1.
```

(c) Event 16: Missile Launch Time

```
EV 15 TNOW= 27 .29964633 ATRIB(1)= 1.
YPOS= 24591.66242727 ALT= 31 . VEL= 247.
HDG= 9 . SRMP= 71146.992 3508 LG= 7
X= 6 . Y= 26361.83873 39 SR= 2096.471155199 D= 3. 4994552047
ANG= 71.84565453916 RC= 1994.447188 44 TIMAC= 2.64 59113 758


TMFO= 2.62773 155526 TLO 27 .3165 72832 TI= 272.94 2374387
RI= 199 .447188344 TRCS= 89.99337 4746E SIGMA= 25.
PKR= .942326 4 2332 CEP= 2 . 9077932368
```

(d) Event 17: Missile Impact Time

```
EV 17 TNOW= 272.9442374387 ATRIB(1)= 1.
YPOS= 24591.66242727 ALT= 31 . VEL= 247.
HDG= 9 . SRMP= 71346.392 3 08 LG= 7
X= 6000 . Y= 26361.83873 39 SR= 1994.478355044 D= -272.533319297
ANG= 90.20354173149 RC= 1994.465769825 TIMAC= .3512574232117
TMFO= .8 98032833339 TLO 272.9442374387 TI= 275.7164 1 754
RI= 21 4. 72147843 TRCS= 1 8.5697372733 SIGMA= 3.7
PKR= .1114 71311733 CEP= 1 5.6195318368
AIRCRAFT 1. KILLED BY RADAR 54.
```

(e) Event 18: Freeing the radar 30 seconds after impact

```
EV 18 TNOW= 302.9442374387 ATRIB(1)= 1.
```

this time. Threat "54" is a type SAM B. Specific data on both the threat and the aircraft are specified below:

Threat 54 SAM B	Aircraft 1 Strike
x coord 60,000 m	initial x coord 0
y coord 26,561 m	y coord 24,592 m
Max FOV 74,150 m	x velocity 247 mps
Min detec rng 305 m	Altitude 310 m
	Heading 090°

Aircraft 1's y coordinate does not change during the mission. Its x coordinate at any time can be determined as follows:

$$x = 247(\text{TNOW}-\text{TCREATE}) \tag{59}$$

where

x = the aircraft's current x position,

247 = the aircraft's x velocity,

TNOW = the current simulation time, and

TCREATE = the time the entity was created by the model.

Aircraft 1's x position at TNOW = 32 seconds:

$$x = 247(32-30) = 494 \text{ m}$$

The Slant Range, SR, to the site can be computed by solving equation (14):

$$SR = \sqrt{(26{,}561-24{,}592)^2 + (60{,}000-494^2) + 310^2}$$

$$= 59{,}540 \text{ m}$$

Thus, Aircraft 1 is inside site 54's maximum detection range of 74,150 m. To be detected, the aircraft must be above the minimum multipath angle, α, of .25 degrees. Solving equation (15) for α, the angle above the horizon becomes:

$$\alpha = \sin^{-1} \left(\frac{310}{59,540}\right)$$

$$= .298°$$

Aircraft 1 is inside the maximum detection range of threat 54, above the minimum tracking altitude of 305 m, and above the .25 degree minimum multipath angle. The model assumes threat 54 has detected aircraft 1. It assigns an acquisition and tracking time of 23.265 seconds. This in between the minimum and maximum times of 12 and 26 seconds. (See Table IV.)

The next event that occurs is event 15 at the end of acquisition and tracking. From the computer printout, event 15 occurs at TNOW = 55.265 seconds or (32 + 23.265). At this time, the site recomputes a SR, and determines numerous quantities including a missile firing time, TLO, a missile impact time, TI, the range from the site to the target at impact, RI, the probability of kill, PKR, the radar cross section at impact, RCS, the aspect angle at impact, TRCS, and the circular error probable, CEP. These

and additional values will now be calculated and compared to the computer printout.

The aircraft's x coordinate at TNOW = 55.265 seconds is calculated:

$$x = 247(55.265 - 30)$$
$$= 6240 \text{ m}$$

Solving for the SR:

$$SR = \sqrt{(26561 - 24592)^2 + (60{,}000 - 6240)^2}$$
$$= 53796 \text{ m}$$

Because the ($x_A < X_S$), the aircraft is located prior to the *closest approach point* (see Figure 11). Solving equation (11) for θ yields:

$$\theta\,(\text{ANGLE}) = \tan^{-1}\left[\frac{26561-24592}{60000-6240}\right] = 2.1°$$

Solving equations (25) and (26) determines the firing conditions:

$$t_{AC}\,(\text{TIMAC}) = \frac{\left[53796 \cos\left(\sin^{-1}\left(\frac{310}{53796}\right)\right)\right] \cos(2.1)}{247}$$
$$= 217.6 \text{ sec}$$

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$$t_{MC}\,(\mathrm{TMFO}) = \frac{\left\{\left[53796 \cos\left(\sin^{-1}\left(\frac{310}{54796}\right)\sin(2.1)\right]^2 + 310^2\right\}^{\frac{1}{2}}}{759}$$

$$= 2.6 \text{ sec}$$

Since $t_{AC} > t_{MC}$, the firing will be delayed (217.6-2.6) seconds or the missile launch time becomes:

$$(\mathrm{TLO}) = \mathrm{TNOW} + (217.6 - 2.6) = 270.3 \text{ seconds}$$

Missile impact occurs 2.6 seconds later or:

$$(\mathrm{TI}) = 270.3 + 2.6 = 272.9 \text{ seconds}$$

For this encounter, the intercept occurs at 90 degrees (ANG=89.99 degrees). The corresponding σ_{RCS} (SIGMA) for a SAM B at a 90 degree aspect angle is 25 dB (see Table V).

Aircraft 1 is wet (jamming). The terms A, B, and C for the CEP evaluation (equation (17)) are:

$$A = 5.62 * 10^{-6}$$

$$B = 2500$$

$$C = 232$$

The term K for equation (20) is -51.4 dB. Solving equations (20) and (21) for J/S yields:

$$J/S_{dB} = 65.97 - 25 - 51.4 = -10.4$$

$$J/S = 10^{-10.4/10} = .0905$$

From equation (17) CEP can be evaluated:

$$CEP = \sqrt{(5.62 \times 10^{-6})(.0905)(1988)^2 + (2500)(.0905) + 232}$$

$$= 21.45 \text{ m}$$

Finally, solving equation (16) for the SAM B's P_k yields:

$$P_k(PKR) = 1 - .5^{(43.6/21.45)^2} = .942$$

Thus event 15 schedules a missile launch time (event 16) for TNOW = 270.3 since the P_k value is greater than the threshold value of .05. The computed R_i is stored in the model as attribute 10 (ATRIB 10). The model will evaluate the ATRIB 10 and a computed value for R_i in event 16 to determine if the aircraft has maneuvered since event 15.

At TNOW - 270.3 aircraft 1's x coordinate is determined as follows:

$$x = 247(270.3-30)$$

The algorithm goes through the same calculations as event 15 to determine a R_i. It then compares this R_i with ATRIB 10. If the Ratio is less than 1.1, the model assumes the aircraft has not turned, where Ratio is defined below:

$$\text{Ratio} = \frac{R_{i_{new}}}{R_i}$$

The algorithm goes through the same calculations as event 15

$$x = 247(270.3 - 30) = 59354 \text{ m}$$

Solving equation (14) for SR gives:

$$SR = \sqrt{(26561-24592)^2 + (60000-59354)^2}$$

$$= 20953 \text{ m}$$

The R_i can be evaluated as follows:

$$\tan\alpha = \frac{\Delta y}{\Delta x} = \left(\frac{26961-24592}{60000-59354}\right) \quad \alpha = 8.9°$$

$$R_{i_{new}} = \frac{\Delta y}{\cos 8.9} = 1991 \text{ m}$$

The model now calculates Ratio:

$$\text{Ratio} = \frac{1991}{1988} = 1.0015$$

Since the Ratio is less than 1.1, the model assumes the aircraft has not maneuvered since event 15. (Note, since aircraft 1 is a strike aircraft and can not turn, the result is expected and the small difference in R_i is attributed to roundoff error). The calculated J/S, CEP, and PKR remain the same as those calculated at event 15. (See computer printout.) Thus the missile is launched at

this time and event 17 (missile) impact scheduled for TNOW + TMFO, or $270.3 + 2.6 = 272.9$ seconds.

Event 17 occurs at the impact time. The model again checks the value of Ratio at impact. The x coordinate, SR, and R_i calculations are depicted below:

$$x = 247(272.9 - 30)$$
$$= 59996 \text{ m}$$

$$SR = \sqrt{(26561 - 24592)^2 + (60000 - 59996)^2 + 310^2}$$
$$= 1994 \text{ m}$$

$$R_i = SR = 1994 \text{ m}$$

At this time the model selects a random number to determine if the aircraft has been destroyed. If the random number is less than the PKR the aircraft has been destroyed and the computer printout annotated.

Thirty seconds later, event 18 occurs and frees the site to search for another target. (See computer printout.)

AAA Calculations

The AAA geometry calculations are the same as those in the SAM portion of the model. The difference between the two algorithms is in the manner the P_k is evaluated. The AAA P_k calculations is determined by solving equations

AAA Probability of Kill Computer Printout

(a) Subroutine SEARCH detects an aircraft

```
RADAR 2. START TRACKING ACFT 5.
AT TIME 243.
TRC= 1?.26292515?84
```

(b) Event 15: At the end of Acquisition and Tracking

```
EV 15 TNOW= 253.26292515 8 ATRIB(1)= 5.
RADAR NUMBER 2.
G= 2.SRK= .71395?431273 SIGAAA2= 2.3.891 37326
VF= 652.?32833687 TOFL= .9216128483649 TI= 254.1845379992
PKSS= .? 3F1 8?1253581 PKR= .155453484 2513
```

(Note: Event 15 calculated an immediate launch. Event 16 is skipped and the Program schedules Event 17.)

(c) Event 17: Scheduled Impact Time of the Round

```
EV 17 TNOW= 254.1845379992 ATRIB(1)= 5.
G= 2.SRK= .71395.431273 SIGAAA2= 2 3.891 37326
VF= 652.?32833687 TOFL= .9216128483649 TI= 255.1?6?5 8475
PKSS= . 361.8?1253531 PKR= .1554534842513
```

(d) Event 18: Freeing the radar 30 seconds after impact

```
EV 18 TNOW= 284.1845379992 ATRIB(1)= 5.
```

(50) through (58). These are highlighted below. (See computer printout.)

The R_i is determined as follows:

$$R_i = \frac{\Delta y}{\cos[\tan^{-1}(\frac{ALT}{\Delta y})]}$$

$$= \frac{24752 - 24108}{\cos[\tan^{-1}(\frac{310}{24752-24108})]}$$

$$= 715 \text{ m}$$

Converting to kilometers:

$$(SRK) = \frac{R_i}{1000} = .715 \text{ km}$$

From equation (51) the velocity of the round at impact is calculated as follows:

$$V_f(VF) = 930 \exp[-.4965(.715)]$$

$$= 652 \frac{m}{sec}$$

Equation (53) uses the Vf to determine the round's TOF:

$$TOF(TOFL) = \frac{2014.46}{652} - 2.166 = .92$$

Each round's dispersion pattern around the target, σ, becomes:

$$\sigma_m = 20R = (20)(.715) = 14.28 \text{ m}$$

and $$\sigma^2 (\text{SIGAAA2}) = (14.28)^2 = 203.9 \text{ m}^2$$

Evaluating the $P_{k_{ss}}$ from equation (57) yields:

$$P_{k_{ss}}(\text{PKSS}) = \frac{5.17}{2\pi(203.9)+5.17} \exp\left\{-\frac{1}{2}\left(\frac{[9.8(1.3)(.92)^2]^2}{2\pi(203.9)+5.17}\right)\right\}$$

$$= .004$$

This leads to the evaluation of the overall P_k for the engagement:

$$P_k(\text{PKR}) = 1 - (1-.004)^{50} = .17$$

Appendix J

Radar Positions in FEBA

```
               ****RADAR POSITIONS***
.
RADAR NO      XPOS  YPOS
.
 AAA RADARS
.
1             50400 34199
2             50400 24100
3             50400 32176
4             50400 17963
5             50400 32657
6             50400 32641
7             50400 21523
8             50400 19700
9             50400 29298
10            50400 33052
11            50400 29662
12            50400 22993
13            51500 38960
14            51500 21746
15            51500 33304
16            51500 31675
17            51500 33404
18            51500 29685
19            51500 21332
20            51500 32896
21            51500 29177
22            51500 29051
23            51500 22353
24            51500 33660
25            52500 28801
26            52500 30996
27            52500 22804
28            52500 41991
29            52500 26124
30            52500 36900
31            52500 26894
32            52500 33800
33            52500 26250
34            52500 33854
35            52500 29342
36            52500 33834
37            53400 40618
38            53400 24048
39            53400 19222
40            53400 22361
41            53400 35624
42            53400 34556
43            53400 27209
44            53400 28209
```

```
45          53400 35772
46          53400 28842
47          53400 35726
48          53400 36906
.
SAM-A RADARS
.
49          95000 29327
50          95000 38470
51          130000 25236
.
SAM-B RADARS
.
52          60000 29323
53          60000 24026
54          60000 26562
55          75000 32949
56          75000 30951
57          75000 36754
48          75000 35640
59          75000 27318
60          75000 11963
.
SAM-C RADARS
.
61          52500 30962
62          52500 34333
63          52500 37129
64          52500 25139
65          52500 29843
66          55000 32399
67          55000 23916
68          55000 36832
69          65000 30801
70          65000 32764
.
SAM-D RADARS
.
71          52500 31075
72          52500 40629
73          85000 31936
74          85000 22967
75          85000 35572
76          110000 35485
77          110000 24159
.
EW RADARS
.
78          55000 26759
79          55000 16385
```

101	80	60000 41162
102	81	75000 35497
103	82	75000 21494
104	83	85000 36311
105	84	85000 18692
106	85	95000 29836

Vitae

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Kenneth C. Anderson was born 7 November 1945 in Warsaw, New York. He graduated from Robstown High School, Robstown, Texas in 1964 and attended Texas A&M University. He graduated in January 1969 with a Bachelor of Science degree in Aerospace Engineering and received his commission. He attended pilot training at Moody AFB, Georgia and became a T-38 instructor pilot. Additional assignments include the Foreign Technology Division as a space systems analyst and Pease AFB, New Hampshire as a FB-111 instructor pilot. He received a Master of Science degree in Management Science from the University of Dayton, Ohio in 1976. Following graduation from AFIT he will be stationed at the Air War College, Maxwell AFB, Alabama.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Defense suppression of enemy ground forces is basic to successful counterair objectives. The F-4G Wild Weasel (WW) weapon system provides the teeth in getting the defense suppression job done--identifying, locating, and killing enemy ground based threat radars. The objective of this thesis was to develop a methodology that could examine and evaluate the WW defense suppression mission.

The problem was developed for a NATO/Warsaw Pact encounter in Central Europe.

A model of the threat environment was built using the SLAM computer simulation language. Threats in the defense sector can be moved as desired. Friendly aircraft can enter the system at a variety of intervals, altitudes, and airspeeds. WWs hunt for threats to attack by searching, identifying, locating, and then launching their weapons at the threat. WW tactics can be changed as the requirements of the mission dictate or at the desire of the WW crew. Self-protection jamming can be selected by either WW or attack aircraft. Enemy threats will fire at an aircraft when the aircraft comes within the threat's range as long as the threat is not engaged with another aircraft. Early warning radars account for threat radar command and control functions; their control over the associated radars can be changed as desired.

Changing the WW's altitude from 60 meters to 200 meters did not effect friendly attack aircraft survivability. Leading the attack force into the threat area by 30 seconds as opposed to accompanying the attack force did not influence attack force survivability. Further development of the model to include turn-mode capability for the WW weapon and a tactic for pre-emptive weapons launch in anticipation of threat radar radiation is recommended.